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ENGINEERING AT THE ENDS OF THE EARTH. POLAR OCEAN TECHNOLOGY FO--ETC(U)
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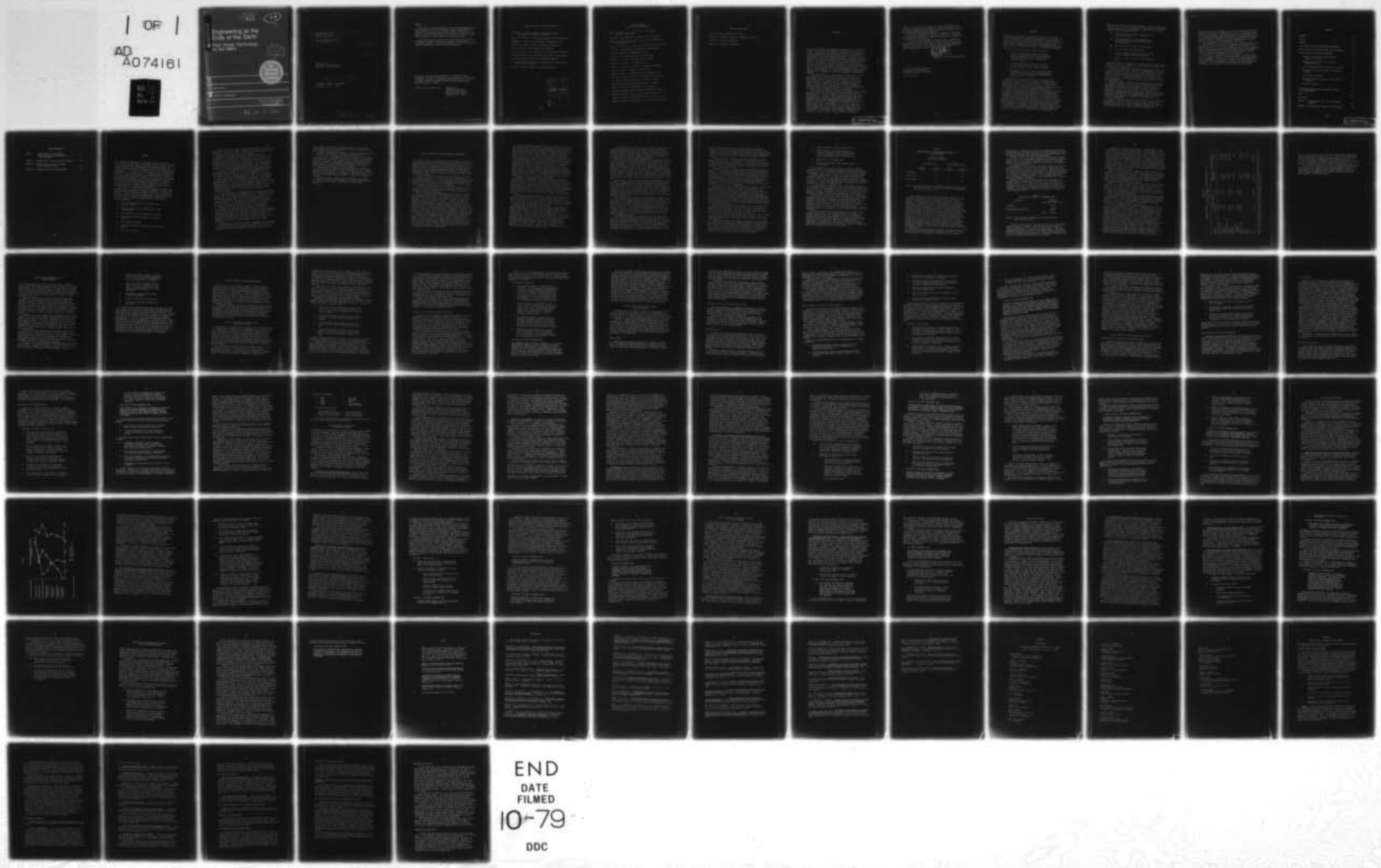

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Engineering at the Ends of the Earth

Polar Ocean Technology for the 1980's

The National Research Council

Marine Board

Assembly of Engineering

(6)

ENGINEERING AT THE ENDS OF THE EARTH

Polar Ocean Technology for the 1980's

(11) 1979

(12) 87p.

Marine Board
Assembly of Engineering
National Research Council

(15) N00014-77-C-0728

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1979

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NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the panel responsible for the report were chosen for their special competence and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by the Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This report represents work supported by the National Science Foundation, the Office of Naval Research, the Department of Energy and the National Oceanic and Atmospheric Administration through Contract No. N00014-77-C-0728 between the Office of Naval Research and the National Academy of Sciences.

Limited copies available from: Marine Board
Assembly of Engineering
National Research Council
2101 Constitution Avenue
Washington, D.C. 20418

PANEL ON POLAR OCEAN ENGINEERING

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FOREWORD

For many decades, U.S. engineering activities in the polar oceans were largely in support of scientific investigations. During the last decade, engineering has taken on greater importance in those areas with the advent of oil and natural gas exploration and production in the Arctic and the expansion of fishing operations. These have been matched by increasing concern with environmental protection and the legitimate interests of the native people of the Arctic. The 1980's, the period covered in this report, will undoubtedly see greater emphasis on polar development as well as on environmental protection, particularly in the Arctic. Accordingly, it will be essential to have adequate engineering capability to complete necessary engineering systems in an economical and environmentally acceptable manner.

The development of polar ocean regions and, indeed, the capability to deal with the rigors imposed by the environment are international objectives. The high priority of obtaining energy and living resources from polar regions is demonstrated by Canada and the Soviet Union in their commitment to advance their technical capabilities in polar operations. Arctic resources are also attractive to nations far from the polar areas, such as Japan and the Federal Republic of Germany.

The widening interest in polar development could well provide the basis for concerted international effort in the coming decade. Several members of the study panel and reviewers of this report have suggested that one means of strengthening technical cooperation and commitment to advancing polar ocean engineering knowledge would be to dedicate the period 1982-1983 as the Centennial International Polar Year, to commemorate the First International Polar Year (1882-1883). It is well known that the 75th Anniversary of the International Polar Year led to the highly successful International Geophysical Year (1957-1958), when significant advances took place in antarctic basic studies. This suggestion deserves

immediate attention as a means to focus the efforts of the United States, United Nations, and cooperative international organizations on polar resource development in an environmentally acceptable manner.

I wish to express my thanks to members of the Panel on Polar Ocean Engineering for their efforts in producing a programmatic approach to improve our national capability in polar ocean engineering.

I also wish to express my appreciation to those who participated in the workshop on polar ocean engineering for their willingness to identify polar ocean engineering needs, as well as to the review committees and staff for their substantial contributions to this report.

William S. Gaither
Chairman
Panel on Polar Ocean Engineering

College of Marine Studies
University of Delaware
Newark and Lewes, Delaware

June 15, 1979

PREFACE

This report is the result of a study of the Panel on Polar Ocean Engineering organized by the National Research Council in October 1977 under its Marine Board, Assembly of Engineering. The study was conducted in cooperation with the National Research Council's Maritime Transportation Research Board and under the sponsorship of the National Science Foundation, the Office of Naval Research, the Department of Energy, and the National Oceanic and Atmospheric Administration.

In undertaking the study the panel was asked to:

- Identify technological capabilities in polar ocean engineering that need to be developed to advance national objectives, such as commercial resource development in polar regions and scientific research.

- Describe technological deficiencies in polar ocean engineering that will need to be eliminated in order to achieve national objectives.

- Recommend the types of research for dealing with the deficiencies in polar ocean engineering that impede both current projects and those projected for the decade of the 1980's.

Accordingly, the panel concentrated on the technological deficiencies and did not attempt to conduct cost-benefit studies or other economic evaluations of the consequences of technological improvements. Moreover, the panel did not directly address institutional problems in carrying out polar programs. Rather, such issues, wherever they arose, were cited for further examination.

The word "deficiencies" is defined as unmet or partially met needs in the areas of technology, data-information systems, and system development. The focus of this study is on the technological deficiencies in polar ocean regions, especially in ice-covered oceans, as contrasted with the general inadequacies of ocean engineering that pertain to both temperate and polar regions. The panel concentrated on defining short-term deficiencies, meaning within a decade, identifying current economic or operational needs, and pinpointing those areas where additional effort might produce significant improvements within the next decade. In consequence, this report's horizon extends to 1990.

The work of the panel was augmented by a workshop attended by experts in polar research, operations, and ocean engineering. The

workshop participants are listed in Appendix A. The workshop was held June 21-23, 1978, at the U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. Experts met in six working groups to identify deficiencies in:

- Living resources assessment, management, and harvest technology;
- Ice, oceanographic, and environmental data for management decisions, predictive models, and forecasting;
- Marine transportation, port and ship design;
- Offshore resource recovery systems;
- Logistics communications satellites, and data systems to support polar operations; and
- Antarctic programs and institutional considerations.

The working groups also suggested the appropriate actions that are most likely to eliminate the inadequacies or shortcomings and analyzed the consequences of such actions.

This report examines the technological deficiencies in both the arctic and antarctic regions. However, the preponderance of discussion is oriented toward the Arctic. This focus was chosen because polar resource development and supporting polar ocean engineering activity will occur mainly in the Arctic during the period covered in this report, the 1980's. Throughout this report, the term "arctic waters" is used to mean all sea ice areas, both arctic and subarctic, in the Northern Hemisphere.

Although the panel recognized that national security, including the strategic importance of the Arctic, is a principal driving force for research, development, and operations, it did not direct its investigation to military needs and the associated deficiencies in technology. The panel was not constituted to undertake such a substantial, complex, and largely special task. However, the general interests and requirements of national security were considered and are incorporated implicitly in the recommendations, especially in those related to the advancement of knowledge and understanding of the particular environment.

The panel was also aware of the political and economic challenges and changes in the Arctic. Within the last decade, the political influence of, first, the Alaska natives and, more recently, those of Canada and Greenland have become increasingly apparent. The Arctic Slope Regional Corporation (ASRC), which was incorporated to

manage and invest its entitlement of 5.6 million acres and $36,000,000 under the Alaska Native Claims Settlement Act, is a growing economic and political influence. Furthermore, the North Slope Borough, which is the native-controlled municipal government incorporated under state law, has taxation, assessment, planning, and zoning authority within its vast boundaries. Undoubtedly, these organizations will assume a strong role in planning the development of the region.

The development of the national resources, the protection of the environment, and the interest of the indigenous populations need to be balanced as the pace of activities quickens in polar regions. The panel considers that a well-reasoned program of polar ocean engineering research and development will contribute significantly to achieving safer and sounder technology that will result in maintaining the balance between polar development and preservation.

This report is based upon many prior studies, on presentations made to the panel by users of polar technologies, and by government program managers, in addition to information and understanding gained from the workshop. A bibliography of previous studies appears as Appendix B. The panel wishes to acknowledge the various sources and the sponsors of this study for their support and encouragement.

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ABSTRACT

SUMMARY

Ocean engineering operations in polar waters, particularly in the Arctic, will increase during the foreseeable future as efforts continue to recover commercially valuable resources such as petroleum, fish, and various minerals. The establishment of the 200-mile economic zone already has resulted in a marked increase in the number and capacity of fishing ships in the Arctic. A sale of leases for the exploration and production of oil and natural gas in the Beaufort Sea is scheduled for late 1979. The petroleum industry is rapidly expanding its technological base in Alaska and Northern Canada. Mining and other operations are planned for Greenland. In the Antarctic, krill resource assessment and experimental fishing projects are being undertaken by several countries in preparation for large-scale development. In addition to U.S. activities, other nations--notably Canada, the Soviet Union, Japan, West Germany, and Norway--are investing substantial funds in developing polar ocean engineering technologies.

This report is a review of polar ocean engineering research and technology that are considered necessary to support of commercial and scientific operations during the decade of the 1980's. In presenting the panel's view of the critical national needs in polar ocean engineering, the report identifies and examines the technical deficiencies in today's state of the art and recommends ways of improving the situation. Critical needs are treated in the report under the following headings:

ABSTRACT

- Resource Identification and Development: Offshore Oil and Gas
- Resource Identification and Development: Renewable Resources
- Arctic Commercial Marine Transportation Systems
- Environmental Data Requirements for Engineered Systems
- Data Acquisition Methods
- Interactions Between the Environment and Engineered Systems
- Polar Ocean Logistics

In the course of the study, the panel also identified a number of nontechnical factors that affect the growth and vitality of polar ocean engineering. Some of the issues are legal and institutional in nature and therefore beyond the expertise of the panel.

Government and industry share many common concerns in the development of ocean and polar resources. Since it is in the national interest for natural resources to be developed in an economical and environmentally acceptable way, the government will need to provide certain services and to undertake certain basic engineering research programs necessary to support such developments. The recommendations to guide such research are summarized below (and appear in greater detail in the section, "Critical Needs in Polar Ocean Engineering").

In the area of nonrenewable resource identification and development, the panel recommends that the federal government initiate a cooperative program to develop the technical capability to support year-round oil spill clean up response in a range of ice conditions.

On the subject of renewable resources, the panel recommends that an arctic vessel safety program should be established to (1) develop the technology necessary to eliminate heavy icing of vessels and equipment and (2) to educate the marine community in safe arctic vessel operating practices. The panel also recommends a modest level of federal support for continued investigations of antarctic krill and for continued research into the potential of using tabular antarctic icebergs for fresh water in specific arid regions, probably in the Southern Hemisphere.

The panel regards arctic commercial marine transportation systems to be of great importance and recommends that a comprehensive assessment be made of such ocean transportation systems. As important subelements in this, the panel recognizes the need to identify criteria for selecting adequate sites for ports in the High Arctic and for designing such ports. The panel also recommends that an examination needs to be made of the feasibility of shallow draft icebreakers for use in nearshore areas and that the relation between icebreaker performance and specific ship characteristics be quantified.

Following its identification of renewable and nonrenewable resources that show economic promise for recovery and export from the polar regions, the panel has considered the need for environmental data for engineered systems. Data is needed to develop predictive models and to understand and characterize the relationship between ice, structures, and seabed soil. Such data will have to relate to ice movements and basin-wide driving forces, large scale ice features, ice mechanics, and the effect of environmental forces on man-made structures.

Once design and operational modeling requirements are identified, the need for advances in data acquisition methods will follow logically. Therefore, the panel recommends that improved remote sensing capabilities should be developed to facilitate the conduct of wide

area surveys, especially for characterizing sea ice. This should include emphasis on polar buoy systems and careful consideration of a polar orbiting satellite system.

The panel recognizes the importance of the design and development of a research vessel capable of operating in marginal sea ice.

While the panel was especially attentive to the effects of the polar environment on engineered structures and systems, it also placed great importance on questions of the effects of engineering systems on the polar environment. Here, singular questions include the long-term effects of spilled oil, dispersants, and burning of combustible hydrocarbons on ice-covered waters and the impact of the disposal of drilling muds and cuttings on the polar environment.

To facilitate the conduct of field operations, the panel recommends that attention be given to polar ocean logistics. This includes defining the requirements for a family of vehicles capable of transporting personnel, supplies, and equipment to offshore locations. Such vehicles include wheeled types, hovercraft, tracked, and air-powered transport.

Finally, the panel recommends the establishment of a national focal point for identifying, recommending, and coordinating solutions to nontechnical, nonscientific constraints on polar resource development.

THE POLAR OCEANS AND THEIR TECHNOLOGICAL DEVELOPMENT

On any map, the Arctic is designated as the ice-covered top of the world, above latitude $66^{o}33'$ N called the Arctic Circle. By contrast, the Antarctic Circle is rarely used to circumscribe the limits of Antarctica at the southern end of the Earth. Piled high with ice and snow, Antarctica is a vast continent surrounded by a stormy sea and characterized by an irregular demarcation known as the "Antarctic Convergence," which meanders between 45^{o} and 65^{o} south latitude and separates the warmer water of the Atlantic, Pacific, and Indian oceans from the polar ocean.

Unlike the Antarctic, which is solid earth under its persistent ice and snow, the Arctic is entirely ocean, only two-fifths of its surface being permanent ice. For the most part, the Arctic is an ocean of drifting ice packs and ice floes, colliding and heaving upon each other, with leads or cracks in the ice and polynyas, or fairly large open stretches, sometimes called arctic lagoons.

The oceans of both regions can be fierce and forbidding. Both have also fascinated, excited, and lured explorers, adventurers, and scientists, as well as businessmen who have visualized the areas as frontiers of commercial opportunity.

One of the earliest recorded conquests of the Arctic Ocean was made in about the year 870 by a Norse adventurer named Ottar, who sailed around northern Norway into the White Sea as far as the Kola Peninsula. Not until the sixteenth century, however, did the great voyages of discovery begin in the Arctic. To avoid the armadas of Spain and Portugal that ruled the southern sea lanes, England sent expedition after expedition in search of northern routes to China and the East Indies. In 1553 Sir Hugh Willoughby sailed across the top of Europe in quest of the Northeast Passage, reaching the Kola Peninsula before his death, while his men went on to Archangel to establish trade relations with Russia. The Cabots, John and Sebastian, sought out the western route to China without success, but did discover Newfoundland.

Perhaps the most heralded exploit of the period took place in the 1570's when Martin Frobisher led three voyages to find a Northwest Passage to China, reported some twenty years earlier by the French mariner, Jacques Cartier, to be somewhere west of Newfoundland. After nearly three years the Frobisher Expedition returned empty-handed, to the dismay of the English bankers and merchants who had paid for it. In the aftermath, however, a large fishing and whaling industry soon developed in the waters of Newfoundland.

Up to the nineteenth century, only a few nations had explored the Arctic seas--England, Denmark, France, Holland, Portugal, and Russia. With limited engineering and scientific knowledge and experience to overcome the cruel sea and heavy weather, the explorers had to rely on their courage, perseverence, and ingenuity. With the end of the Napoleonic wars in 1815, Britain sought to expand its commercial markets and its military dominance, in part with explorations of the Arctic and Antarctic. Captain John Ross made several unsuccessful attempts between 1815 and 1833 to find a northwest passage through the polar region of Canada. His nephew, James Clark Ross, following the charts Captain James Cook made between 1773 and 1775 in circumnavigating the Antarctic, got through the ice pack and in 1841 took possession for Britain of a section of the Antarctic continent and several islands. During James Ross' three voyages between 1839 and 1843, scientific parties collected biological specimens--though the harsh conditions and rudimentary techniques contributed to inaccurate readings and spoiled samples. The Ross Expedition began the race to claim the Antarctic. By the start of the twentieth century, seven nations went on to stake territorial claims there.

Meanwhile, technology was advancing the range and capability of polar exploits. In the 1890's, ships were reinforced to withstand limited encounters with the ice, though many hulls were still smashed in the polar sea. A notable exception was the ship "Fram," which Fridtjof Nansen navigated into the arctic pack ice in 1893, and which drifted across the polar ocean with the ice and finally, in 1896, broke free off Spitzbergen with little damage. The hull of the "Fram" had been designed to be lifted by the ice, as well as to withstand the forces of the drifting ice--one of the first examples of polar marine engineering.

In the late nineteenth century, it became obvious that much more scientific understanding and engineering competence were needed to explore and develop the Arctic. As a part of the International Polar Year of 1882-1883, nine European nations, the United States, and Canada conducted a series of polar conferences and field operations to advance science and technology primarily for the Arctic.

The Russians, notably, made advances in polar transportation and engineering, beginning in 1899 with the icebreaker "Ermak," under Admiral Stepan Makarov. In 1910, Russia launched annual hydrographic cruises off the Siberian coast by the icebreakers "Taimyr" and "Vaigach" and in 1914 first used radio for communication in the Arctic. The long-sought goal of reaching the Bering Sea from the Atlantic by a polar route was finally achieved in 1906 by a Norwegian, Captain Roald Amundsen, after a three-year voyage in the "Gjøa" while he was performing geomagnetic and biological surveys. In the Antarctic, Captain Robert Scott commanded a large British expedition in the "Discovery" from 1902 to 1904. Beaten to the North Pole by an American, Lieutenant Robert E. Peary, in 1904, Amundsen raced Scott to the South Pole and reached it first in 1911.

In the mid-1920's, aircraft of the U.S., Norway, Britain, and the Soviet Union arrived in both polar regions. One of the earliest flights by Commander Richard E. Byrd and Floyd Bennett reached the North Pole first in 1926 in a Fokker monoplane, "Josephine Ford." As the nation with the largest frontier in the Arctic, the Soviet Union has used aircraft widely for transport, reconnaisance, and rescue operations, developing considerable capabilities.

Because of its need to keep a northern sea route open for most of the year, the Soviet Union is preeminent in the development and use of large icebreakers. In 1932, the icebreaker "Sibiryakov" was the first vessel to complete the voyage across the Siberian polar ocean, from Archangel to Yokohama in one season. In a remarkable technological advance, the "Lenin," the first of a new class of nuclear powered icebreakers, went into service off Siberia in 1964. In August 1977, the nuclear icebreaker "Arktika" reached the North Pole, and the following year the "Sibir" cleared the way for a Soviet freighter to traverse the polar ocean in a straight line from Severnya Zemlya to Wrangel Island, a distance of 2,300 nautical miles, much shorter than the usual coastal route.

Nuclear power for vessels was pioneered for submarines, not icebreakers. In August 1958, the world's first nuclear submarine, "Nautilus," submerged under the ice pack and cruised across the North Pole for 1,830 miles before it came up between Greenland and Spitzbergen. Eight days later, another U.S. nuclear submarine, "Skate," surfaced at a break in the ice pack near the North Pole. The nuclear submarine has demonstrated that it is a breed apart, differing from its predecessors as much as steamships differed from sailing vessels. It portends important scientific and military applications in the polar ocean, and possibly commercial uses.

With the discovery of petroleum and natural gas in Alaska, the pace of technological development has accelerated in the polar regions. The transit of the Northwest Passage by the 1,007-foot oil tanker "Manhattan" in 1969 demonstrated the feasibility of bulk marine transport in the polar oceans. Important experience has been gained in recovering oil in the harsh ice conditions and strong currents of Alaska's Cook Inlet. Such advances notwithstanding, much more needs to be known to develop the technological capability to deal with large pressure ridges, seabed ice scouring, and multiyear ice, which are being encountered as oil and gas operations take place in the polar ocean off Alaska and Canada.

Recent Canadian research and development has included construction of artificial islands for drilling in shallow arctic waters, under-ice pipelaying and connection methods, drilling from artifically thickened floating ice "platforms", and designing drill ships that can operate in drifting ice and icebergs. The use of icebreakers for extending the operating season of drill ships is under consideration. Although the construction of a powerful Canadian icebreaker of class 10, capable of breaking ice 10 feet thick (the "Arktika" is class 7),

has been deferred indefinitely, such an icebreaker (estimated to require 150,000 shaft horsepower) could be used to extend the time available for exploratory drilling, now limited to a few summer months. It could also be used as a pusher ship to enable tankers equipped with special icebreaking bows and stern adapters to navigate the Northwest Passage.

In the Antarctic, activities are directed predominantly toward exploration and science. Over exploitation of whales and seals, brought some species to near-extinction. Restriction of seal hunting by international agreement has enabled an appreciable recovery and the possibility exists that sealing, at least, could resume for specific species on a managed quota basis.

Antarctic krill are being evaluated as a potential protein source because of their abundance. Russia, Japan, Poland, and the Federal Republic of Germany are conducting resource assessment studies as well as research on krill harvesting and processing technology. Another abundant antarctic resource, icebergs, is being considered as a source of fresh water which could be towed to arid regions of the world. Areas of the Antarctic Ocean that offer the greatest petroleum potential are the Ross and Weddell Seas and the Bellinghausen Basin, although other areas cannot be ruled out. There, glacial ice shelves and areas of heavy sea ice are extensive.

The Antarctic Treaty of 1959, which opens the entire continent and its surrounding sea to scientific research without prejudice to territorial claims and prohibits military operations and certain nuclear activities, does not cover the region's resources. Therefore, the only deep drilling now explicitly permissible is geophysical drilling for scientific purposes. Those nations that have signed the Antarctic Treaty have deferred the questions of hydrocarbon exploration and development for future solution. As the twentieth anniversary of the treaty approaches, many nations are exhibiting increasing interest in the Antarctic's potential mineral wealth, despite the logistical and ecological problems posed.

Antarctic ice consists mainly of annual ice, 1 to 3 meters thick, with embedded pressure ridges. Tabular bergs, broken from the ice shelves, are also embedded in the pack ice. Some icebergs may work their way to the outer edge of the pack ice and into the open ocean, reaching 60° south latitude and even farther north.

The offshore areas of the Antarctic are characterized by seas with waves of long intervals so that the peak energy occurs at very low frequencies, by storms of high frequency, fierce winds, and extremely low temperatures.

A number of technological problems are encountered during geophysical drilling in the Antarctic, including logistics, navigation, communications, and position-keeping and the design of a stable platform for seas with long wave periods and for withstanding ice conditions. This platform should especially have the ability to move off-station rapidly. Various innovations for the Arctic may be applicable to conditions in the Antarctic, including the development of:

- Larger dynamically positioned drill ships;
- Risers capable of safe operations under antarctic conditions (this is under consideration for the National Science Foundation's proposed 1980-1990 Deep Sea Drilling Project);
- Capability to tow icebergs; and
- Special caisson vessels with dynamic positioning capability.

In the longer term, it may be possible to develop floating structures capable of submerging 250 meters or more beneath antarctic iceberg keels. At this depth year-round operations would be possible; the submerged structure could avoid storms as well as tabular bergs.

Drilling through antarctic shelf ice is made difficult by the movement and thickness of ice, which may be 200 to 300 meters thick. Also, drill holes tend to close under the high pressures that develop in the ice. Thus, although geophysical drilling is currently conducted from shelf ice, albeit with some difficulty, techniques are still required for deep drilling from shelf ice.

All these factors, in addition to the international controversy that surrounds possible resource recovery in the Antarctic, underscore the conclusion that development of the Antarctic will occur more slowly than in the Arctic. Furthermore, little economic incentive exists for antarctic development because recent conferences on the extension of the Antarctic Treaty have deferred questions about mineral resources.

In the Arctic, however, the current development of offshore energy resources is the major motivation for polar ocean engineering. Other non-energy resources will undoubtedly be developed when economically feasible. Undiscovered oil and gas resources in the Arctic are estimated to be considerable. The wide range between conservative and optimistic estimates listed in Table I is an indication of the preliminary state of knowledge of arctic petroleum resources. Extensive field operations will be necessary to provide more accurate resource assessments.

Oil and gas operations in the polar region will require the development of artificial ice-resistant structures, and perhaps, subsurface completion techniques, transportation of oil production equipment and personnel, cargo shipment, and improved communications. Several alternatives have been suggested for transporting oil and gas from offshore, including buried pipelines, surface ships, semisubmersibles, and submarines. Submerged oil production and storage facilities and terminals may be another option. Tunnels extending from shore to the production area may be still another.

TABLE I

ESTIMATED RANGE OF UNDISCOVERED RECOVERABLE OIL AND GAS RESOURCES

in Arctic Alaska
(offshore and onshore)

	OIL (billion barrels)		GAS (trillion cubic feet)	
	95% Probability	5% Probability	95% Probability	5% Probability
Bering Sea	0	8	0	18
Arctic Ocean	2	19	5	50
North Slope	5	16	14	49

Source: Adapted from "Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States," U.S. Geological Survey, Circular 725, 1975.

Aside from the economics of any arctic venture and the required supporting technologies, alternative systems may be favorably or unfavorably judged on the basis of impacts on species of fish and wildlife, on their habitats, on the natural environment, and on the dependence of indigenous peoples on these resources. In addition, identification of the most favorable alternative will also depend on new technological developments in ice prediction; increased understanding of pressure ridges and bottom ice scouring; advances in sea floor engineering, pipe line installation, oil pollution prevention and cleanup techniques; and knowledge of seabed permafrost conditions. Moreover, the types of port facilities and service industries that evolve will be closely linked to the transportation modes used in oil and gas operations. The need for specific supporting facilities or systems such as remote arctic natural gas liquefaction facilities, undersea manned terminals, and more capable and versatile icebreakers as well as icebreaking tankers can only be determined as resource development proceeds. However, relevant supporting research needs to be done now if resource recovery is to proceed in a coherent and timely way sometime soon.

Initially, in order to minimize exposure to hazards such as ice-scouring, oil and gas exploration in the polar ocean north of Alaska will be conducted at shallow depths, perhaps within the 12-meter

depth contour. A lease sale in this area is scheduled for late 1979. As experience and technology are developed and as geophysical studies uncover promising new areas, exploratory drilling and development may be expected to progressively move into deeper water.

The first sale of oil and gas leases in the Bering Sea is scheduled for 1982. In the Bering Sea, exploratory drilling can usually be carried out with conventional technology during the ice-free summer season. Year-round production operations will require new technology to cope with drifting pack ice.

In preparation for oil and gas lease sales, resource assessments are now underway in the Beaufort Sea, Bering Sea, Chukchi Sea, and Norton Sound. Even after the sale of the leases, exploratory drilling and lease evaluation will take several years. If commercial resources are discovered, several more years, perhaps a decade, will pass before oil or gas can be brought to market. This development phase will require significant advancements in polar ocean engineering to support year-round production operations.

Besides oil and gas reserves, numerous coal fields exist in northern Alaska, although much of the coal is of low quality, as is evident in Table II. In order for coal resources to be developed commercially, the costs of extraction and transportation will have to be reduced. With vast coal resources more readily accessible in the "lower 48" states, extensive commercial development is not likely to take place in the 1980's.

TABLE II
ESTIMATED COAL RESOURCES OF NORTHERN ALASKA

COAL TYPE	RESOURCES (millions of short tons)
Bituminous	19,292
Sub-bituminous and Lignite	100,905
TOTAL	120,197

Source: "Coal Resources of Alaska," U.S. Geological Survey Bulletin 1242-B, 1967.

The Arctic also contains considerable deposits of hard and placer mineral resources.[1] However, there has been a steady decline in arctic mining activity from its peak in 1916 because of high costs, inadequate transportation, and short operating seasons. Although the Seward Peninsula will continue to be an active mineral resource area, polar ocean engineering requirements for continuing operations are not expected to be significant during the next decade.

Large-scale fishing is likely to spur the development of polar ocean engineering. Arctic fishery resources include high unit value species such as cod, pollock, ocean perch, black cod, salmon, herring, and crab. Living ocean resources of the Antarctic include the protein-rich, low-unit-value krill. With the establishment of the 200-mile economic zone, U.S. fisheries will expand into offshore Alaskan fishing areas which have been dominated in the past by foreign fishing operations (See Table III). As the technology is developed for operating closer to the edge of sea ice, safer operations will result and longer fishing seasons will occur. The expanding Alaskan fishing industry may be expected to extend into the more remote and environmentally harsher fishing areas as rapidly as vessel safety and resource conservation and management practices will allow.

Much of the technological development for polar activities is dependent on scientific research. Many of the pioneering polar explorations have had scientific components. Collecting specimens, studying conditions, and measuring such properties as temperature, salinity, ice density, and sea changes were pursuits of many expeditions, in the belief that better understanding of the polar oceans is central to mankind's increasing mastery of the regions.

Research is often stimulated by practical needs. Thus, one important series of research projects followed from a great tragedy, the sinking of the "Titanic," which struck an iceberg in 1912. It led to studies of polar currents and iceberg dynamics, as well as to the founding of the International Ice Patrol to keep watch on the hundreds of icebergs that break from the Greenland icecap every spring and cause a hazard to North Atlantic shipping.

Polar research was one of the major activities of the International Geophysical Year of 1957-1958, when data were gathered and exchanged by more than 300 research stations among the participating 67 nations. Today it is clear that the polar regions have entered a new era--the great age of discovery ended earlier in the century and the age of development is beginning, slowly but inexorably.

As polar development patterns emerge, engineering and scientific research needs become better defined. An increasing number of research programs are being directed toward improving polar logistics and engineering capabilities. The principal conference that addresses polar ocean engineering activities is the biannual International Conference on Port and Ocean Engineering under Arctic Conditions (POAC). Four conferences have been held to date, and a fifth conference is scheduled for August 1979 in Norway. To a limited extent, the Offshore Technology Conference has addressed some polar ocean engineering problems. Similarly, other specialty engineering conferences, such as the International Conference on Permafrost held in 1978 in Edmonton, Canada, deal with polar ocean engineering topics. In 1971, the U.S. Office of Naval Research (ONR) conducted an arctic ocean technology assessment workshop. The same year ONR co-sponsored with the U.S. Defense Advanced Research Projects Agency (DARPA) a symposium on arctic logistics support technology. Other recent polar engineering conferences and studies have included the International Conference on

TABLE III

FOREIGN FISHING IN THE U.S. FISHERY CONSERVATION ZONE (1978)
(Metric Tons)

Species	GULF OF ALASKA Allocation	GULF OF ALASKA Catch	BERING SEA and ALEUTIAN ISLANDS Allocation	BERING SEA and ALEUTIAN ISLANDS Catch
Atka Mackerel	22,000	19,429		
Pacific Cod	2,300	2,455	55,300	36,466
Flounder	20,500	18,588	204,800	121,937
Herring Ocean Perch	---	---	19,400	18,736
Pollock	149,000	121,274	950,000	888,552
Rockfish	33,000	23,996		
Sable fish			7,200	4,634
Southeast	3,750	3,677		
Other	11,750	11,811		
Other Finfish	16,200	4,570	93,600	68,243
Crabs			12,500	12,471
Snails			2,700	404
Squid			10,000	8,316
TOTAL	258,500	205,800	1,355,500	1,159,759

Source: Data obtained from "Fisheries of the United States, 1977," Current Fishery Statistics No. 7500, National Oceanic & Atmospheric Administration, 1978.

Sea Ice in Reykjavik, Iceland in 1971; the International Conference on Materials Engineering in the Arctic, which took place in Quebec, Canada in 1976; the Polar Transportation Requirements Study conducted by the U.S. Coast Guard in 1968; NATO's Arctic System Conference at St. John's, Newfoundland, Canada in 1975; and Arctic Institute of North America's Conference on the Coast and Shelf of the Beaufort Sea.

The Canadian government is currently undertaking two studies which bear on polar ocean engineering. The Canadian National Research Council is conducting a study on research and development for ocean engineering in cold regions, while Transport Canada is conducting a study on marine transportation of oil and liquid natural gas from arctic islands to commercial markets.

IDENTIFYING CRITICAL NEEDS IN POLAR OCEAN ENGINEERING

Polar ocean engineering is driven by several factors, including resource exploration and development, national security and strategic considerations, and scientific research. In identifying the critical needs in polar ocean engineering, the panel sought first to identify the technological deficiencies and then to group related recommendations into program areas. While the likely benefits of remedying these deficiencies were considered, the panel made no attempt to conduct cost-benefit analyses.

The panel distinguished between the roles of government and industry in polar ocean engineering development by positing that industry would need to perform activities to advance commercial operations and that the government would need to undertake activities necessary to establish policies to promote healthy polar resource recovery industries, ensure that resources are developed at a pace and in a manner that is in the public's best interest, and provide appropriate environmental and support services for commercial operators, government regulators, certain military activities, and the general public.

Furthermore, the panel recognized the complementary roles of the commercial sector and the government, and concluded that both sectors share a strong interest in the rapid development of all polar ocean engineering technology. The panel is satisfied that in most cases where commercial activities are well established, such as in oil and gas development, the industry is undertaking projects to perfect the equipment and processes it needs to conduct its operations. As a result, this report contains few recommendations that apply directly to the private sector.

Government policies, programs, and regulations, as well as the outcome of various treaty negotiations, are closely related to the continued advance of technology useful in the polar regions. While the panel discussed these issues and recognized their potential for encouraging or inhibiting future development, it concentrated on examining technological concerns that it considered were hindering the development of polar ocean engineering technology.

This report sets forth programmatic recommendations that the panel finds necessary to strengthen and direct polar ocean engineering research. Each programmatic recommendation attempts to meet five tests for effectiveness. Accordingly, each recommendation needs to:

- Be within the panel's charge to identify deficiencies in polar ocean engineering or, if not a purely technical recommendation, be related explicitly to that charge;
- Meet an economic or scientific need (a user must be clearly evident for the improved technical capability that would result from implementation of the recommendation);
- Be adequately supported with relevant technical information;
- Present a clear course of action; and
- Be realistic within the time period of the 1980's.

In the following sections of this report, the panel first identifies certain critical needs that hold promise of advancing polar ocean engineering so that it can better serve those concerned with commercial resource recovery and scientific research efforts. The next section deals with transport facilities to support polar ocean operations and move the resources to processing plants or to markets. Following that is a section on the need for information about and understanding of oceanic and atmospheric conditions, as well as polar predictive models of environmental behavior that are certain to have a cause and effect relationship to resource development facilities and transportation systems. Then comes a section on the acquisition of environmental data in polar regions and the equipment and systems that will gather such data. Finally, the report deals with several nontechnical factors that the panel considers likely to directly influence polar ocean technology advancement in the 1980's.

CRITICAL NEEDS IN POLAR OCEAN ENGINEERING

The users of polar ocean technology comprise four major groups -- resource developers, scientific investigators, those concerned with national security, and those organizations that provide transportation and logistics to support either offshore activities or land-based operations in polar regions. Diverse technologies are common to each. For example, all require similar data to plan resource use and development activities and to conduct day to day operations. Accordingly, scientists may be concerned with understanding ice movement phenomena, industries with the availability of transportation, the Coast Guard with safety and navigation, and the Department of Defense with national security.

This chapter discusses the critical needs that the panel identified and groups these programmatically as: resource identification and development for offshore oil and gas and for renewable resources; environmental data requirements for engineered systems; data acquisition methods; interactions between the environment and engineered systems; and polar ocean logistics. For each of these subjects, deficiencies are identified and analyzed, conclusions are drawn, and recommendations are made.

Resource Identification and Development: Offshore Oil and Gas

Development of technologies for the production of oil and gas from the offshore Arctic encompasses such complementary activities as scientific investigations of arctic ice, including its properties, movements, and related environmental characteristics; federal efforts to assess the extent of the resource and the hazards associated with recovery; and efforts by industry to develop capabilities to conduct successful exploration and production operations. The fabric of this latter activity is interwoven with governmental regulatory matters that are intended to assure that exploration and production are undertaken with due regard for human safety, resource conservation, and environmental protection.

This section deals primarily with technologies related to exploration and production of oil and gas that are of mutual concern to government and industry. Technologies for the acquisition of environmental engineering data and the development of fundamental understanding of the interactions between the environment and engineered

structures are considered in detail in separate sections. What is needed in the way of environmental data and understanding are improved weather and ice forecasting techniques for offshore operations, environmental assessment programs about extreme operating conditions that could lead to better facility design, studies of the distribution and properties of offshore permafrost and other geotechnical conditions related to foundation design, and research in sea ice mechanics, and ice model testing for the purpose of predicting ice forces and bearing capacity.

Considerable research is being conducted by the petroleum industry to extend offshore oil and gas capability further into the arctic region. Arctic marine oil and gas technology has evolved from production platforms developed and installed in the Alaska's Cook Inlet in the mid-1960's. Those structures were designed to resist the forces of moving ice fields, strong tidal currents, and earthquakes. Much advanced research and development has taken place in Canada.

Significant accomplishments have been made in exploration drilling methods, often employing novel techniques tailored to specific environmental conditions in both arctic and subarctic sea ice. To date, sea ice drilling has been conducted from:

- Temporary artificial islands made of gravel, sand, silt, or ice, founded in shallow water fast-ice areas of Mackenzie Bay in Canada and off the North Slope of Alaska;
- Artificially thickened floating ice platforms used in deep water fast-ice areas of Canada's arctic islands;
- Ice-strengthened floating drill ships, drilling during the short summer in Canada's Beaufort Sea; and
- Dynamically positioned drill ships using iceberg detection, towing, and avoidance systems in deep water iceberg areas off Labrador and West Greenland.

A production subsea gas well in the Canadian Arctic has been completed using novel through-the-ice pipe laying and connecting techniques.

A range of other technologies for exploratory drilling and for oil and gas production from the arctic continental shelf are at various stages of industrial development. These include methods for laying gas pipelines of large diameters across ice-covered channels in the Canadian Archipelago; air-cushion platforms for drilling in deep water, fast-ice areas; mobile gravity structures for exploratory drilling in shallow arctic pack-ice areas; and icebreaking tankers for transporting

oil or liquefied natural gas from the Arctic to North American markets.

Before the onset of commercial offshore oil and gas operations, the government is responsible for assessing the resource potential and evaluating the possible hazards, as well as for the lease sales of public lands. Once commercial operations begin, government responsibility extends to assuring that every private developer takes into account the safety of personnel, conservation of resources, and protection of the environment. The government also is obligated to detect and monitor offshore oil spills and to take appropriate pollution response action.

Arctic oil and gas operations are prone to long lead times and logistical difficulties. In conducting arctic oil and gas lease sales, the government will find it necessary to consider these realities in the design of lease and operating requirements.

Because of the manner in which arctic petroleum resources are being explored and developed, and the division of responsibilities between government and industry, the panel has identified specific technical deficiencies in oil and gas operations only in the area of prevention of and response to emergency situations, where the responsibilities of government and industry overlap.

Oil Spill and Fire Fighting Response Capability

Even with the best equipment, operational procedures, and safety inspections, oil spills, blowouts, and well fires may occur. In addition, accidents or malfunctions may occur in marine transport systems such as tankers or pipelines. The task of recovering spilled oil is often slow and difficult, particularly in conditions of broken and drifting ice. Fire fighting and well killing are hampered by freezing temperatures, heavy seas, and drifting ice. Thus response technologies and capabilities for dealing with harsh environmental conditions are especially needed for the Arctic Ocean.

While technological requirements for fire fighting and blowout control in ice-covered seas are not currently being addressed by the federal government, the U.S. Coast Guard sponsors research to improve oil spill detection, containment, and cleanup capabilities. The Coast Guard maintains a mobile strike force that participates in the cleanup of major spills. This group is gaining experience in oil spill response and improving its ability to detect spills and operate cleaning equipment. Also, several private corporations develop, build, and operate cleanup equipment. However, while considerable oil spill response and cleanup technology has been developed by both industry and government for use in mild conditions in open water, improved technology is still needed to cope with rough seas and ice-covered waters, particularly for unstable ice conditions when the pack ice freezes, breaks up, and drifts.

Advances in spill containment and cleanup capability are needed to support year-round Arctic Ocean operations and the extension of offshore operations beyond the zone of stable fast ice. New technologies for controlling blowouts and well fires in the Arctic would reduce the exposure to such hazards.

The panel concludes that:

- In general the industry is taking the steps necessary to develop appropriate equipment and facilities for the exploration and development of potential offshore petroleum resources in the Arctic. The panel concludes that it will be cost-effective and in the national interest for industry to continue this development and for government to be fully informed of industry's programs and progress in this activity.

- A need exists for the government to take arctic operating conditions and extended time scales into account in applying regulations to these regions. Thus, the government should emphasize the development of a simplified, flexible regulatory regime for resource development in the Arctic.

- Responsive management strategies need to be instituted to assure the timely transfer of required information among the user groups, including government agencies, the industrial and commercial sectors, the scientific community, local communities, and other interests.

- Engineering deficiencies exist in oil spill cleanup and blowout control technologies for the polar ocean. A concentrated effort will be necessary to develop response systems that perform reliably in sea ice.

Therefore, THE PANEL RECOMMENDS THAT:

THE GOVERNMENT SHOULD INITIATE A COOPERATIVE OIL SPILL RESPONSE RESEARCH PROGRAM TO IMPROVE CAPABILITIES FOR FIRE FIGHTING AND BLOWOUT CONTROL IN ICE-COVERED SEAS AND TO IMPROVE OIL SPILL DETECTION, CONTAINMENT, AND CLEANUP OPERATIONS IN SEA ICE. THE ULTIMATE GOAL OF THIS PROGRAM WOULD BE TO DEVELOP THE TECHNICAL CAPABILITY TO SUPPORT YEAR-ROUND OIL SPILL RESPONSE FOR A RANGE OF ICE CONDITIONS, INCLUDING MOVING PACK ICE AND STORMY SEAS.

An oil spill response research program should include development of predictive models for oil spill movement and dispersion in arctic waters. Input for these models may require additional environmental assessment information, such as data on subsurface ice morphology and currents. Remote oil spill detection equipment should be developed so that the extent of an oil spill may be quickly delineated. Fire fighting and blowout techniques should be reviewed to determine their applicability and shortcomings under arctic offshore conditions. Finally, containment and cleanup equipment should be developed that can operate under all ice conditions and sea states. This equipment may include shallow-water icebreakers, air-cushioned vehicles (ACV's) equipped with oil skimmers and incinerators, and under-ice containment and withdrawal equipment. Such alternatives to mechanical cleanup as burning of spilled oil in-situ and the use of non-toxic dispersants should be further developed and tested. Testing of equipment and cleanup methods could be best accomplished as part of the controlled oil spill field tests recommended elsewhere in this report. Much of this work could be undertaken jointly by industry and government.

Resource Identification and Development: Renewable Resources

Implementation of the Fishery Conservation and Management Act of 1976 has spurred rapid development of U.S. crab, ground fish, and herring fisheries in subarctic waters, especially in the eastern Bering Sea. Currently, it is estimated that more than 200 U.S. fishing vessels are operating in the eastern Bering Sea throughout much of the year.

A variety of technological developments are frequently proposed to enhance U.S. competitiveness in world fisheries and to pursue under-utilized nonconventional species, such as antarctic krill. The U.S. fishing fleet is technically capable of exploiting conventional species, such as cod, hake, flounder, crabs, shrimp, and salmon, to list a few, with existing domestic and foreign fishing technology and vessels. Therefore, deficiencies in the capability to hunt and harvest the conventional species seem to relate to the safety of fishing operations in polar conditions.

Vessel Icing

Vessel operations in polar regions can be severely limited by spray ice formation on decks, superstructure, rigging, nets, and lines. Not only does ice restrict the use of the vessel, it also creates an unsafe and unstable work platform. Each winter, several

vessels capsize, frequently with loss of life, as a result of becoming top heavy and unstable when the deck gear and superstructure is laden with ice. Such conditions exist even though there have been design rules promulgated for several years by the American Bureau of Shipping and other classification societies to ensure safe vessel design for arctic operations.

Additionally, some materials and techniques, such as special plastics and the use of waste heat, have been investigated and show promise for application to icing problems. Advances in ice prevention and removal capability will lead to greater safety and operational efficiency, and also to lower operating costs of the commercial arctic fleet. The loss of life and vessels can be lowered also through education and more exacting licensing requirements. The rapid increase in the number of steel vessels in Alaskan waters over the last five years, coupled with the projected increase over the next five years, attaches special importance to the development of adequate defense against icing hazards.

Education in Arctic Vessel Operating Practices

With the expansion of U.S. commercial operations in the Arctic, merchant seamen and fishermen without prior cold weather experience or special training are encountering vessel icing problems and ice navigation problems for the first time. Under such conditions, an increase in vessel casualties may be expected.

The directions for sailing in arctic waters include a brief discussion of icing conditions. The Inter-governmental Maritime Consultative Organization (IMCO) has recently issued safety codes for fishermen, which include more extensive arctic provisions. The panel found no special arctic training or examinations required of ship masters prior to sailing in polar waters.

Antarctic Krill

To date, the U.S. has not participated actively in developing ocean technology for harvesting antarctic krill. While krill is one of the largest latent animal protein sources known to exist in the ocean constituting the major food source of many whales, seals, fish, squid, and birds, the degree to which the U.S. uses it will depend on the commercial potential, including joint ventures with foreign companies. Large quantities of krill currently exist because the whale and seal populations have been depleted. Without an increase in the number of whales, in particular, krill may be expected to become even more abundant.

Currently, technology for krill harvesting is being developed by Soviet, Japanese, Polish, and German interests. In addition, some processing equipment critical to overall operations has been supplied

by U.S. industry. Experience to date suggests that advances in engineering are needed to develop means of locating krill by acoustic techniques and in the reliable operation of conventional trawl nets and trawl doors in areas of ice coverage.

Negotiations for a new Antarctic Treaty have resulted in interim guidelines for the conservation of antarctic marine ecosystems not now covered.[2] The guidelines call for countries to cooperate in exchanging living resource data and to show the greatest concern and care in harvesting living resources to prevent the depletion of antaractic marine stocks or to jeopardize the ecosystem in any way.

By tracking technological developments in the krill fishery, the U.S. can keep up-to-date on economic and scientific information needed to determine commercial opportunities and to monitor ecological changes occurring in the area. Someday, krill fishing may become highly automated. Innovative production techniques may have far-reaching commercial benefits for the U.S. but unknown ecological consequences that could radically upset the entire marine ecosystem in the Antarctic.

Tabular Antarctic Icebergs as a Water Resource

More than three-fourths of the earth's freshwater supply is locked in polar ice. The antarctic ice sheet appears to be in a state of near equilibrium, with snow accumulating over the continent, compacting, and flowing outward as glacial ice. At the edges of ice shelves, the outflow "calves" as icebergs. The icebergs could be towed off without affecting the steady-state cycle of the Antarctic. Substantial quantities of bergs could be removed without adverse effect on the earth's albedo and hence without serious climatic effects.

However, substantial problems exist in towing icebergs to areas where fresh water is needed. For example, melting and possible breakup would occur during the transit. There are questions, moreover, about conversion of the iceberg to water at its destination.

Recent estimates suggest that it should be possible to furnish water from antarctic icebergs to the South American and Australian deserts and perhaps to some Middle-East countries at less than the cost of desalination. It is not yet clear, however, whether icebergs can be utilized as an economical freshwater source for the southwestern United States.

Among the considerations involved in the exploitation of antarctic icebergs are:

- Developing technology to extract icebergs of 1 km or larger from the pack ice and to cut large bergs to appropriate towing size;
- Developing suitable iceberg towing and mooring systems (towing speed would have to be on the order of 1 to 1.5 knots);

- Identifying the effects of currents, Coriolis forces, and wind on the navigation of icebergs;

- Developing means such as encapsulation or insulation to prevent iceberg breakup and loss of water through melting and evaporation during transit;

- Developing capabilities for bringing icebergs into harbors and mooring them;

- Controlling iceberg melting and containment of fresh water at sea; and

- Resolving legal and navigational restrictions that may relate to icebergs in tow.

The techniques necessary to achieve these several capabilities are considered attainable if the activities are found to be economically justified. By keeping up with developments and pursuing a modest level of investigation, the U.S. will be able to keep open the option of benefiting from this potential freshwater resource. It needs to be re-emphasized that U.S. technological capability to move icebergs is more likely to benefit countries in the Middle-East and Southern Hemisphere than arid regions of the U.S. However, the effort could stimulate the U.S. maritime industry as well as provide a commercial technology exchange with those nations most likely to put the resource to direct use.

The panel concludes that:

- Technological deficiencies in fishing practices are not handicapping the development of arctic fisheries. Rather, in certain instances, there has been a failure to take advantage of technological advancements that have occurred in other parts of the world.

- The principal technological deficiencies in U.S. arctic fishing activities are in dealing with the factors that influence operational safety and are associated with icing and vessel movement in fringe ice.

- Keeping apace of activities by other countries engaged in the assessment and development of krill resources will enable the U.S. to maintain an assessment of the species as well as of potential opportunities in commercial krill operations.

- It is now uncertain if it is practical and economic to use icebergs for potable water, and the uncertainty may persist for some time, until user requirements are better defined.

The panel concludes that a modestly funded research program should be continued to determine the technological feasibility and economics of utilizing tabular icebergs as a fresh water resource. Study efforts should address melt problems, calving, breakup and instability, attachment and towing techniques, and processing techniques. The investigations should be of a limited nature until the interests and requirements of potential users become better defined.

Therefore, THE PANEL RECOMMENDS THAT:

THE FEDERAL GOVERNMENT SHOULD UNDERTAKE AN ARCTIC VESSEL SAFETY PROGRAM. SUCH A PROGRAM WOULD INCLUDE SHIP ICING DEFENSE AND ICE NAVIGATION TRAINING FOR ALL PERSONNEL CONCERNED WITH VESSEL SAFETY. THE OBJECTIVES OF THE PROGRAM WOULD BE TO PROVIDE TECHNOLOGY NECESSARY TO ELIMINATE HEAVY ICING OF WORKING VESSELS AND EQUIPMENT AND TO EDUCATE THE ARCTIC MARINE COMMUNITY IN SAFE OPERATING PRACTICES IN THE POLAR OCEAN.

The proposed ice defense program should be developed in close coordination with maritime and fishing industries, classification societies, and state governments. The types of arctic vessels that encounter icing problems should be analyzed in detail with respect to icing hazards. Techniques that might be applied to prevent or limit icing or to remove hardened ice should be analyzed, taking ship characteristics into account. Such techniques may include: application of proposed ice-preventing coatings to deck surfaces and standing rigging; use of available heat from engine exhausts, engine coolants, and such mechanical sources as piped water grids; and the use of electrical generating capacity and such electrical devices as heat tapes. Techniques for removing ice, such as ultrasonics, should also be investigated. At the same time, increased fuel requirements and costs must be considered.

To assess the feasibility of various ice prevention and removal techniques, several ships will need to be equipped with different types of ice prevention and removal systems. The performance of the different systems would then be evaluated and compared under operating conditions. As one aspect of this evaluation, the rules of classification societies will have to be reviewed to make sure the design margin for stability and associated costs is adequate to meet successful ice defense techniques.

The Coast Guard, with support and cooperation from other interested agencies, should initiate an education program on safe practices for vessels operating in polar waters. Operational

procedures used by other countries should be taken into account in developing the Coast Guard's program. For example, the Intergovernmental Maritime Consultative Organization (IMCO) has recognized icing hazards problems and issued special safety codes for fishermen.[3] Consideration should be given to requiring all U.S. vessel masters and mates operating in cold regions to complete the education program and to be licensed to ensure that safe operating practices are known for arctic conditions.

The results of the field experiments, the feasibility analysis, and the training program should be reviewed to determine what further efforts should be taken to develop an adequate ice defense program for arctic vessels.

For the Antarctic, the panel holds that the federal government should continue to support investigations into the ecology of marine resources and continue its participation in negotiations leading to the proposed convention for the conservation of living marine resources. In preparation for this convention, U.S. interests in antarctic krill resources need to be reassessed, especially for the development of harvesting and processing technologies. The U.S. should keep abreast of technological developments for detecting, harvesting, and processing antarctic krill and continue or even increase its participation in studies aimed at a better understanding of the southern ocean ecosystem. Such studies should include determining the optimum sustainable yield for the krill harvest. The panel has noted that, under the leadership of the Group of Specialists on the Living Resources of the Southern Ocean, substantial progress is being made toward developing an international program along the lines recommended in the report, "Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS)."[4] This group of specialists is sponsored jointly by the Scientific Committee on Oceanic Research (SCOR), the International Association of Biological Oceanography (IABO), the Advisory Committee for Marine Resource Research (ACMRR) of the United Nations Food and Agricultural Organization, and the Scientific Committee on Antarctic Research (SCAR).

Arctic Commercial Marine Transportation Systems

Commercial Marine Transportation System Development

Arctic marine transportation systems evolving over the next decade will probably be largely dependent upon activities associated with the exploration and production of oil and gas, coal, and mineral resources. Coastal communities, including those that service the resource development activity, will require dependable marine transport. The new transportation systems will include ships, barges, pipelines, offshore and onshore terminals, and other associated marine facilities.

With the notable exception of barged cargo and logistics support from the West Coast of the U.S. to the North Slope of Alaska during the

summer season, there has not been a demonstrated need or national commitment for developing commercial cargo-carrying marine transportation systems for polar regions. The voyages of the "Manhattan" and the construction of a large ice-breaking barge and a Canadian 28,000-ton arctic bulk carrier indicate, however, that there is increasing technical capability and interest in developing and operating commercial arctic surface vessels.

In temperate regions, water transportation is typically the least expensive means, in terms of economics and energy, for transporting bulk commodities over considerable distances. Consequently, marine transport might reasonably be expected to be the leading means for the most reliable, efficient, and economic shipment of bulk commodities between arctic and temperate markets. Yet the development of an all-weather marine transportation system to support arctic resource development has been deterred by three principal factors:

- Environmental obstacles such as shifting ice fields and ice ridging.
- The existence of pipelines, a specialized alternative transportation system with advanced technology and reduced risk.
- Insufficient economic impetus, such as a proven and producing bulk commodity of sufficient magnitude to warrant the assumption of the risks associated with development of a new transportation technology.

Despite these barriers, as resource development expands in Alaska and northern Canada, it is expected that these obstacles will be overcome and marine transport will provide an improved alternative for bulk shipments.

Arctic Marine Transportation Requirements

Engineering and economic assessments of the projected needs for arctic marine transportation must consider the deterring factors listed above. In addition, the requirements for resource transport, construction supplies, and general cargo have not been projected for the industrial, commercial, or community development of the Arctic. Alternative transportation systems to meet the various requirements have not been identified or evaluated either on the basis of the technologies or economics. An organized, comprehensive analysis of transportation requirements that focuses on technology feasibility and cost would contribute to an appreciation of the most efficient, appropriate, and timely polar transportation systems.

Port Facilities

Operation of polar vessels will require advances in port and navigational systems. All-weather operation is the ultimate goal. Substantial research has been conducted on polar environmental problems that affect port design, such as ice characteristics and undersea permafrost. Even so, much of this research is not directly applicable to port design and construction. As a result, structural analysis must still employ rough pragmatic guidelines, which sometimes lead to over-design and higher cost. For example, many arctic marine structures are designed for an ice pressure of 300 to 400 psi, with varying ice thickness. The only justification for using this range of pressure values is that experience has shown that structures designed with these pressures have withstood severe ice forces. Recognizing the wide range of variability in ice strength, the statistical prediction of extreme events is needed for more cost-effective predictions of ice forces.

Moreover, insufficient data are available for addressing the unique problems associated with siting, designing, construction, and maintaining polar coastal and port facilities. There are no accurate means, as yet, for predicting or selecting harbor sites to minimize the effects of ice on port operations. The effects of excavations, causeways, and nearshore man-made islands on ice and pressure ridge formation and on biological and shoreline processes are not sufficiently understood. Furthermore, techniques are needed to prevent erosion caused by ice scouring along banks and channels. Techniques are also needed to extend port operations in all seasons. This can be accomplished by developing techniques to inhibit the formation of ice in harbors and by acquiring knowledge of the characteristics of materials and equipment with respect to their damage by or resistance to the cyclical cold and the sometimes abrasive environmental conditions. Finally, data are needed for the development of analytical and physical models for predicting the effect of the polar environment on coastal installations.

Development of commercial marine transportation in polar regions will also require the identification of ports of refuge from storms and ice damage.

Navigational Assistance

Because most Coast Guard icebreaking operations are directed at maintaining deep-water channels, available icebreakers generally have too large a draft to be able to assist in extending the open period of shallow nearshore waters and harbors in an effective and safe manner. Moreover, shallow water icebreakers are not available in the U.S. Instead, barges have been equipped with icebreaker bows, and tugboats, while limited in maneuverability, have been able to move these barges in shallow, ice-covered waters in the Arctic.

Shallow draft icebreaking capability would provide greater efficiency in the maritime movement of supplies to shallow offshore installations and to coastal harbors, thus avoiding over-ice lightering complications. This would reduce the reliance on more costly transportation alternatives such as air transport. It would minimize the need to suspend operations when shallow waters are ice-covered.

Design Data for Icebreaking Vessels

There are few standard design data to predict a vessel's performance in ice. Such data exist for conventional vessels not operating in ice. A common data base is not available for systematic evaluation of the effects of ship characteristics on their operations in ice. Such a data base is needed for making decisions at the feasibility design stage of small ice-research vessels and icebreaking escort vessels, as well as for large cargo carrying vessels. This data would provide extensive benefits for the arctic marine industry. A systematic evaluation of parameters could lead to more efficient design and more intelligent tradeoffs in the design process, thus resulting in more cost-effective construction.

The panel concludes, accordingly, that:

- Year-round commercial bulk marine transportation and supporting services are not presently available for many offshore and onshore regions of the arctic that are prospective oil or gas producing areas. Likewise, year-round general marine cargo transportation is not available for many villages and towns.

- While pipelines provide adequate transportation for oil from the onshore Prudhoe Bay area, alternative transport may be necessary elsewhere because of geographic, environmental, engineering, economic, and institutional factors.

- The absence of alternative commercial polar marine transportation technology may discourage or even effectively preclude comparison of pipelines to surface or subsurface systems.

- Existing ship capabilities and icebreaking techniques and facilities are inadequate to assure the safe, timely movement of vessels on a large scale.

- Other deficiencies are the absence of technological and economic assessments of the requirements

for various types of transportation systems; significant gaps in the knowledge and technology required to develop effective and reliable polar port facilities; lack of design data for icebreaking vessels; inadequate shallow water icebreaking capability.

Therefore, THE PANEL RECOMMENDS THAT:

THE GOVERNMENT SHOULD UNDERTAKE A COMPREHENSIVE PROGRAM TO ASSESS ARCTIC MARINE TRANSPORTATION REQUIREMENTS AND PROMISING ALTERNATIVE TRANSPORTATION SYSTEMS, INCLUDING SURFACE WATERBORNE SYSTEMS, UNDER-ICE SYSTEMS, AND OVER-ICE SYSTEMS.

Continual technical refinement and economic assessment of alternative polar marine transportation systems is needed in order to provide:

- Sufficiently accurate information for the development of polar transportation systems; and
- A sound technology base for timely response to the need for commercial polar marine transportation.

The panel expects that the major phases of such a program would include:

- Preliminary assessment of potential marine transportation systems based on transportation requirements and analysis of economic, technological, and institutional factors.
- Identification and investigation of technologies and comparative risks of various alternatives.
- Design and performance of experiments where necessary to evaluate the feasibility of satisfying critical, high-risk technology needs.
- Investigation of long lead time and critical technology needs.

Federal leadership in the initial program phases seems most appropriate. However, close coordination with the private sector will be imperative to assure the thoroughness and validity of the program. As the time approaches for the development of a specific transportation

system, the government should encourage implementation by the private sector. Thus, aggressive industrial participation should also be fostered. To the extent possible, a comprehensive polar transport system development program should be coordinated closely with appropriate foreign governments. The panel recognizes the need for case studies of ports and coastal works, to be undertaken in cooperation with appropriate foreign countries. The knowledge that has been gained in other cold regions would be valuable for application to new arctic port development. Case studies should be made of several selected high arctic ports. The purpose of the case studies would be to assemble information on site selection, design, construction, and operation criteria specific to polar ports and to highlight particularly difficult port engineering problems that may be encountered at high latitudes. The participation of Canada, Norway, Greenland, Iceland, and the Soviet Union would be of particular value in conducting such case studies.

In conjunction with the case studies, an arctic port and coastal engineering research program should be undertaken to focus research efforts on identified problems.

In conjunction with the commercial transportation systems study already recommended by the panel, and in close cooperation with the State of Alaska, potential harbor sites should be identified consistent with resource transportation needs and engineering site selection criteria. Ports of refuge and escape routes to open water also should be identified.

Concerning icebreaker design, the panel holds that a determination should be made of the technical and economic feasibility of shallow draft icebreakers for operations near shore and in harbors of the Arctic. Of special interest is an analysis of shallow draft icebreaking vessels and icebreaking bow-equipped barges that have been developed in other nations such as Finland. Alternative icebreaking systems such as the bow-mounted air cushion vehicle (ACV) and self-propelled ACV's should be assessed for their applicability to ice conditions in arctic inshore waters and harbors. The long-term need and performance characteristics for icebreaking in arctic inshore waters and harbors should be assessed, possibly in conjunction with the recommended arctic transportation system study. If the studies show that the alternatives identified in this study have merit, a technical development program should be undertaken to solve identified technical problems.

In ship design, the panel finds that a systematic series of tests need to be carried out to determine the relation between icebreaker performance and specific ship characteristics. Such tests should investigate the effect of the following types of parameters on

icebreaker performance:

- Beam	- Bow Angle
- Draft	- Dead Rise
- Taper	- Power
- Length	- Hull Roughness
- Flare	- Tonnage/Momentum

The program should cover:

- Small research vessels	- Twin screw vessels
- Medium rigid escort vessels	- Triple screw vessels
- Large-size cargo vessels	- Four screw vessels

This test program should be undertaken after progress has been made in standardizing model testing techniques.

Environmental Data Requirements for Engineered Systems

Prerequisite to the deployment of engineered systems in polar regions is an understanding of the effects of the harsh environment on all their parts. The most stable and moderate environment for engineered structures in polar regions is underwater, where the temperature does not go below 28° Farenheit approximately. In this setting, the polar ocean engineer is concerned with the interactions of ice with the structure or, in some instances, the ice-structure-seabed relationship. In addition, the engineer also is concerned about the selection of materials for durability and elasticity, as well as their thermal or other necessary properties over wide temperature ranges.

Accordingly, predictive modeling is an essential aspect of engineering design. At least two conditions must be considered in all designs: (1) response to extreme events that may test whether the structure remains steadfast or succumbs to damage or destruction and (2) behavior under normal operating conditions.

The following sections address, first, the need to understand basin-wide ice movements and driving forces; second, large-scale ice features; third, ice mechanics; and, finally, the interactions between the ice, the structure, and the soil of the seabed. Each is examined on the assumption that predictive models, based on a thorough understanding of the phenomena involved, are needed by the polar ocean engineer. Once the model is developed, statistically valid data are essential.

<u>Ice Movement and Basin-Wide Driving Forces</u> Sea ice covers some areas of the polar oceans all of the year and other portions part of the year. Ice covers the continental shelf of the Beaufort Sea for about nine months of each year. Fast ice, which forms an extension of

the land, is found along the coast. Fast ice grounds out to the two meter depth contour a few kilometers from shore; beyond that it floats. Floating fast ice extends out to the 10 to 20 meter contour, reaching a thickness of about 2 meters. Beyond the fast ice, seasonal pack ice extends to the edge of the continental shelf some 100-150 km offshore from the Alaskan North Slope. Pack ice can occasionally drift into ice-free waters. The deep central Arctic Ocean is covered with permanent pack ice.

Sea ice surrounding the antarctic continent is seasonal and one-year old or less, except for multi-year ice in the Weddell Sea. Floating shelves of glacial ice occur along one-half of the antarctic coastline and comprise nearly 15 percent of the antarctic ice cap. From time to time, sections of these shelves break off to form large tabular icebergs.

Sea ice characteristics and behavior pose serious and substantial engineering problems in the design and operation of vessels and offshore structures. Emplacing buried pipelines on arctic shelves, designing arctic marine transportation systems for the future, and developing placer mining on polar continental shelves and fisheries in the Bering and Chukchi Seas all require better knowledge of sea ice than is now possessed. Attacks on long-range scientific problems in the Arctic and Antarctic Oceans also require the collection of physical environmental data. For example, to gain understanding of climatic change, scientists need to know the effects of ice-covered oceans on the atmosphere. Therefore, observations of polar oceans and atmosphere will be required to test new climatic theories.

How best to calculate many important environmental factors from the standard meteorological data available presents many uncertainties. For instance, surface winds are usually calculated from the geostrophic wind field. In the Arctic, however, unusual conditions such as the persistence of strong inversions make such calculations uncertain without verification by direct measurement and without a well-verified boundary layer model for such conditions.

Another subject that is not understood is the role of ice cover in the generation, development, and subsidence of storm surges. Ice carried toward land by such surges is potentially destructive to structures, pipelines, and the shore area. Winter storm surges may also be hazardous to either low freeboard or lightweight drilling platforms, such as artificial ice islands or grounded barges, which may be used for winter drilling in stable fast ice. Understanding and forecasting such surges can be important in determining the engineering specifications for and location of coastal structures.

The limited availability of field data has not permitted ice dynamic models to be tested sufficiently to acquire a high degree of reliability. This is particularly evident when a variety of time and space scales are considered, which can range from days to weeks and from tens of miles to thousands of miles.

It stands to reason that a high-quality environmental forecasting and analysis program, coupled with rapid dissemination of information to operators in the field, would be useful to many polar operations. Improved long-term forecasting of extreme environmental conditions, on

the order of 5 to 10 years, are likely to be linked to hindcast reinterpretations. This could significantly influence design criteria for offshore construction. Such hindcast studies would also contribute to reliability of transit time estimates and economic assessments of proposed polar sea routes. Long-term forecasts would improve the ability to schedule projects for shipping in years when ice conditions are expected to be favorable. Fishing fleet operations near the edge of the pack ice could improve operations if meteorological and icing hazard reports and forecasts were available. Information on icing rates would be particularly valuable. To be useful, this information must be presented in a clear and precise format that could be related easily to marine charts.

Large-Scale Ice Features Data must be collected on large-scale ice features, including sea ice thickness and roughness distributions, movement of landfast ice,* ice gouging, and permafrost.

Data about sea ice are insufficient both on geographical and temporal bases to meet the demands of a variety of applied problems. Such problems include estimating peak forces on offshore structures, conseqences for surface vehicles and ship routing, probabilistic analysis of ice scoring of the sea floor, verification of different possible ice redistribution functions in models of sea ice dynamics, calculation of the heat budget of the Arctic Basin, and prediction of the attenuation of underwater sound.

To satisfy a wide variety of prospective users, observational data are needed to accurately delineate spatial and temporal variations in ice thickness, including ridge height, depth and width, and ridge spacing; surface roughness; and polynya distribution. In some cases, extensive but unanalyzed under-ice roughness data are available from submarine observations and data.

Information is scarce on extreme ice features such as pressure ridges, floebergs,** ice islands, and icebergs. Data are lacking on the physical and strength characteristics of ridge keels. A tested method is needed for rapidly obtaining such information from large areas of pack ice. Techniques are also needed for extrapolating such data to estimate extreme values for a number of design parameters in the offshore Arctic.

Sea ice thickness and roughness data, coupled with ice dynamics calculations, can contribute to improved and safer designs of offshore

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*Landfast ice is sea ice that is attached to the shore, an ice wall, an ice front, shoals, or grounded icebergs. Fast ice may extend a few meters or several hundred kilometers from the shore and may be more than one year old. Some fast ice may respond to environmental forces by moving a few meters, in some cases up to 100 meters horizontally.

**A floeberg is a massive conglomeration of multi-year pack ice (large multi-year pressure ridge fragment).

structures. In addition, this data could aid in the validation of current models of the redistribution of ice caused by ridging. Validation of such models would reduce the need for field measurements of ice characteristics. This capability could also be extremely useful to those concerned with the measurement and prediction of underwater sound attenuation along different transmission paths in the polar ocean. The direct contribution that improved knowledge of sea ice would make a wide variety of existing and potential applications ranging from offshore structural design to understanding world climate change emphasizes the need for such information.

Landfast ice moves in response to the coupling between the drifting pack ice and the landfast ice edge and to regional meteorologic and oceanographic influences. No adequate method now exists for quantifying these relationships. A predictive model for landfast ice motion would be a valuable tool to warn of impending ice motion. Development of a data base and model for landfast ice would be of help in designing and taking appropriate measures to protect offshore installations from landfast ice damage and in designing petroleum production systems, as well as for predicting potential ice movements.

Ice gouges are a pervasive feature of the sea floor along the Arctic Ocean coast. They are the result of grounding or dragging of ice keels. At present, the frequency of occurrence, maximum possible depth, and forces involved in creating gouges are not known sufficiently to prepare a statistical evaluation of the gouging hazard. The composition and strength characteristics of the keels are likewise not sufficiently quantified. Thus, to be protected, equipment must be buried to a depth exceeding the maximum observed depth of penetration of gouges, plus a safe margin. A better understanding of ice gouging could permit a better estimate of how deep to bury subsea structures. This would reduce the construction effort and cost of sea floor installations.

Offshore permafrost is known to be extensive on the Beaufort Sea shelf, where its occurrence and distribution have been studied for several years. Even so, a number of questions regarding the regional distribution and properties of offshore permafrost remain to be answered. Additionally, the areal extent of clay overburden and its effectiveness in preserving near-surface permafrost need further clarification. It is also of interest to determine the amount of excess ice, if any, that may be present in frozen subsea sediments. Information on bottom sediments and subsea permafrost is essential to the design and safety of offshore structures and pipelines.

<u>Ice Mechanics</u> The characteristics of sea ice depend in part on bubbles and brine, which in turn depend on such properties as temperature, salinity, and structure. While various yield criteria and failure theories have been proposed for specific applications, and model testing has been used extensively in designing ships and structures, the shortcomings in modeling ice properties and the lack of standard testing procedures hamper both the interpretation of model test results and comparisons between different investigations. The

basis for extrapolating small-scale laboratory test data to field conditions requires further development and verification. Furthermore, little data exists on the bulk strength of ice features such as annual or multi-year pressure ridges, which may interact with offshore structures. Accurate information on the physical characteristics of ice are likely to lead to cost-effective design and to help form a basis for the establishment of appropriate certification guidelines.

Theoretical methods for anticipating conditions leading to sea ice structural failure and its ultimate strength are in a preliminary stage of development. The strength of sea ice depends on such factors as temperature, crystal size and orientation, salinity, rate of stress or strain, and sample size. Ice forces can also be characterized in terms of failure mode (such as bending and crushing), ice and ice and structure geometry, and confining pressure. The design of offshore structures in the polar ocean also must take account of other structural loads caused by environmental forces such as earthquakes, waves, and storm surges, accompanied by ice. Thus, the base of offshore structures may be founded in frozen or non-frozen sediments and the upper sections may be locked in sea ice. How such a structure responds to seismic excitation remains to be determined for various conditions. Similarly, the wave and ice forces acting on massive gravity structures in shallow water also must be quantified.

<u>The Effect of Environmental Forces on Engineered Structures</u>

Limited validated data are available about the frequency and magnitude of ice forces on marine structures in polar regions, particularly under extreme variations in environmental conditions, including large tidal fluctuations, high winds, storm surges, and the unexpected movement of large pressure ridges or consolidated ice. In addition to the static and dynamic forces resulting from the sea ice itself, data is needed to determine a combination of forces such as earthquakes in conditions of ice cover or wave action in broken ice cover. Also, certain limitations on the available methods for predicting wave-induced loads on fixed offshore structures may make these methods unsuitable for the design of massive gravity structures for shallow water arctic applications. Empirical data are needed to validate the engineering methods.

Available means are inadequate for predicting ice forces on ship hulls and ice resistance to motion. Predictors are especially inadequate for ice ridge-induced forces, which often are the critical design loadings. As a result, ship designs tend to be conservative and expensive.

At present, determinations of expected ice forces on ship hulls, resulting from the movement of ice and ship relative to each other, are made by means of small-scale tests with laboratory models. Such tests are carried out in several U.S. and foreign laboratories. Because each laboratory uses its own techniques, differing and sometimes incompatible full-scale extrapolations are often obtained. The reliability of these tests is uncertain for several reasons: (1) inadequate knowledge of ice fracture mechanisms and ice strength; (2) meager understanding of ice ridge mechanics and the strength of ice ridges; (3) uncertainty

about the requirements for model ice; and (4) shortcomings of available model ice material. Better understanding of the effect of ice forces on ships would lead to vessels of lower cost as well as improved performance.

A coordinated environmental forces program that provides accurate information to design engineers could expedite offshore development in the Arctic. It would also help to ensure that structures are designed and constructed safely and cost-effectively.

Arctic offshore development requires the use of construction and other materials in a harsh environment. The properties and durability of steel, concrete, and other potential construction materials at low temperatures need to be known before reliable, cost-effective engineering design of offshore structures can be undertaken. For a variety of materials and coatings, the data are insufficient or inadequate on strength and fatigue properties when they are subjected to frequent freeze-thaw cycles, friction, abrasions, and corrosion in cold water. For coatings that may be applied to reduce ice structure interactions, reliable methods are lacking to provide adequate bond strength between the coatings and the substrate in both initial application and subsequent recoating in the field. Inadequate data on material properties could delay the use of construction materials that otherwise would be the most economical choice for a given application. The task of optimizing the design and cost-effectiveness of arctic offshore structures, as well as their certification, would be facilitated if properties and performance criteria of potential construction materials were well known and understood.

Based on its deliberations, the panel concludes that:

- Solid scientific understanding and knowledge of arctic ice conditions are necessary to characterize the environment for the purpose of assessing the potential environmental effect on offshore construction, operations, and transportation;

- Knowledge and understanding are particularly deficient with regard to:

  - Characterization of ice movement and basin-wide driving forces to facilitate environmental forecasting and analysis;

  - Large-scale ice features, including sea ice thickness, roughness, and extreme ice-feature distributions, motion of landfast ice, ice gouging, and permafrost (in particular the extent of clay overburden and its associated insulative characteristics);

  - Sea ice mechanics; and

- Effects of environmental forces on engineered structures, including offshore structures, ships, and engineering materials used in polar ocean applications.

Therefore, THE PANEL RECOMMENDS THAT:

EFFORTS BE MADE TO IMPROVE MODELS FOR PREDICTION OF BASIN-WIDE ICE MOVEMENT AND DRIVING FORCES IN ORDER TO SUPPORT ENVIRONMENTAL FORECASTING FOR OFFSHORE EQUIPMENT OPERATIONS, DESIGN, AND FOR SHIP ROUTING IN THE BERING, CHUKCHI, AND BEAUFORT SEAS.

Research efforts should include meteorological studies of the behavior of the atmospheric boundary layer in polar regions. Particular emphasis should be directed to determining the extent to which strong inversions modify the capability to predict the surface wind field from the atmospheric pressure field.

Adequate ice dynamics models are needed to provide the underpinnings of cause and effect analysis on a basin-wide scale as well as of local predictions for ship routing, offshore operations, and the hindcasting of extreme events. The study should include efforts to simplify the models for many applied problems, to determine the sensitivity of model outputs to a variety of inputs, and to extend the period of reliable forecasts. The study should be oriented to developing models that provide meaningful information to potential users in a convenient, compact, and self-explanatory way.

The panel maintains that it is important to study the effects of wind stress on floating ice cover, the transfer of that effect to the water mass, and resulting under-ice wave motion. Specific areas that need attention include:

- Modifying existing numerical models of storm surge behavior to account for ice cover effect;
- Modeling the properties of wave motion under the nearshore fast ice;
- Comparing results of the models with appropriate laboratory experiments and field observations;
- Developing from historical data or by hindcasting the recurrence intervals and extreme values of potentially destructive surges.

In addition, THE PANEL RECOMMENDS THAT:

WIDE AND SYSTEMATIC AREA SURVEYS BE CONDUCTED TO PROVIDE SEASONAL AND REGIONAL DATA ON LARGE-SCALE ICE FEATURES IN COASTAL AREAS OF HIGH INTEREST. PRESENT STUDIES OF ICE GOUGING AND PERMAFROST SHOULD BE EXPANDED.

In achieving this, a sea ice thickness and roughness distribution research and data collection program should be initiated to systematically obtain profiles of ice surface roughness in order to analyze these. Roughness statistics and the correlation between surface and subsurface profile information should be investigated to a greater degree than has been possible thus far.

The development of sensors for aircraft and space satellites should be encouraged to monitor ice roughness and thickness. Moreover, techniques should be devised for distinguishing between first-year and multi-year ridge keels. In addition, under-ice roughness and thickness sensors should be developed for use in shallow water.

The data base on extreme ice features should be expanded to facilitate the execution of meaningful statistical analyses which may be required for establishing design criteria and operational procedures related to environmental hazards. To enlarge the data base the following actions should be undertaken:

- Support applied research programs to study the size, shape, and strength characteristics (particularly the macro-strength of keels), distribution, and drift of extreme ice features, as well as the development and evaluation of remote sensing techniques such as satellites, aerial photography, and subsurface profiling. Develop an airborne ice thickness measurement system, such as nano-pulse radar, for surveying multi-year ice floes. Update newly acquired data in order to expand the comparatively short-term data base.

- Perform statistical analyses on the data base to estimate probability distribution functions, encounter frequencies and reoccurrence intervals.

- Investigate promising means, if any, of destroying extreme ice features by explosive, chemical, mechanical, and thermal methods, and explore improved collision avoidance schemes.

Landfast ice motion research should consist of complementary experimental and theoretical approaches. Ice motion, pressure, and strain data from numerous points on pack ice and adjacent landfast ice will be required, as well as associated meteorological and oceanographic data. Sensor types, quantity, and placement should be determined as a result of theoretical as well as practical experimental considerations. It is suggested that early field studies center on the Beaufort Sea area.

The study of ice gouges should be expanded to emphasize their frequency and physical characteristics. Repeated surveys of reference

gouges (either natural or plowed for the purpose) would provide data for evaluation. Determination of the maximum depth of penetration, as related to the forces developed, may require modeling and experimental programs.

Regarding offshore permafrost research, present programs should be continued. Information transfer and cooperation between various investigators should be encouraged to obtain maximum benefits of focusing on multidisciplinary data needs.

In this connection, THE PANEL RECOMMENDS THAT:

AN INTENSIVE PROGRAM OF RESEARCH IN SEA ICE MECHANICS BE UNDERTAKEN TO IMPROVE THEORETICAL AND EMPIRICAL MODELING OF ICE FORCES ON SHIPS AND STRUCTURES.

Research on the mechanical behavior of sea ice should be undertaken to develop a useful stress-strain law and failure criteria for various types of failure modes. Standardized testing procedures are also needed for measuring sea ice strength properties. The research program should include:

- Systematic investigation of the strength of *small-scale sea ice samples*;

- In-situ testing of large samples to evaluate failure criteria and provide a basis for extrapolating small-scale laboratory test results to field conditions;

- Determination of bulk strength properties and failure modes of annual as well as multi-year pressure ridges. How such ridges transmit forces to structures should be analyzed theoretically, as well as tested by appropriate models.

To improve the understanding of ice forces on ships, a research program consisting of laboratory testing, development of analytical models, and coordination of field and laboratory data should be undertaken to:

- Evaluate the reliability and determine the deficiencies of laboratory test data obtained with various model ice materials and testing techniques by comparing available prototype and corresponding model-test ice force data;

- Develop an improved model ice material if the deficiencies identified for existing model ice are insurmountable;

- Conduct direct comparison model material tests by using promising materials from the prior evaluation and by using standardized tests and model scales; and compare the results to known prototype data;

- Explain the mechanics of ice-ridge formation, with the objective of developing improved predictors for ice-ridge dimensions and composition (e.g., sail height, keel depth, voids, and blocks) and the forces exerted on ships by ice ridges;

- Conduct a series of tests, using a standard or improved model ice material, to produce benchmark data on ice resistance of a series of idealized ship hulls of different lengths, beams, drafts, and block coefficients.

In summary THE PANEL RECOMMENDS THAT:

A RESEARCH AND DEVELOPMENT PROGRAM BE INITIATED TO ADDRESS THE EFFECTS THAT SUCH OFFSHORE POLAR ENVIRONMENTAL FACTORS AS FATIGUE, COLD, ICE ABRASION, AND COMBINED WAVE AND ICE IMPACT MAY HAVE ON THE PROPERTIES OF ENGINEERING MATERIALS.

A comprehensive research and development program should be undertaken to assess and provide information regarding the effects that environmental forces may have on structures under various environmental conditions. The program should include but not be limited to:

- A survey of present methods for analyzing the interactions of sea ice and structures and other environmental forces on polar offshore structures;

- Collection and analysis of applicable existing data;

- Distribution of state-of-the-art data through a recognized or responsible agency or technical society;

- Identification and acquisition of newly required data, which may place demands for new instrumentation techniques.

At the same time, research needs to be supported on the properties and wear characteristics of structural materials applicable to the arctic offshore. Emphasis should be placed on the strength, fatigue, and surface properties of concrete and on the adhesion and wear properties of coating materials for both concrete and steel. Other areas of interest include low temperature and corrosion effects on steel structures.

Data Acquisition Methods

Predictive models for engineering design and operating use require accurate data collected over an adequate period of time and modeling concepts based on a thorough understanding of the phenomena being modeled. Normal lead time for oceanographic data acquisition for a specific problem may be on the order of five to ten years. The logistics and ice conditions of polar regions complicate data acquisition and result inevitably in increased time and cost.

Oceanographic sensors used in the temperate zones are also used in the Arctic, but with considerable inefficiency and operating difficulties. In ice conditions, instrument installation, survival and recovery, data recording, and data communication all become extremely difficult.

One of the environmental factors that contributes to the low survivability of instruments is ice. Paradoxically, this is one of the elements for which the greatest amount of data is and will be needed to support resource development. Cold air and water temperatures also greatly reduce the reliability of instrument systems.

Physical, geophysical, chemical, and biological oceanography at high latitudes require special techniques not in use elsewhere. New and more efficient methods are needed, therefore, for profiling salinity and temperature and for ocean floor coring below the ice cover, as well as for monitoring currents, turbidity, plankton, and nutrients in arctic and antarctic waters. Synoptic data collection in the Arctic Basin and along its rim can be so unreliable and costly that little effort has been expended to acquire routine meteorological data needed to aid in understanding continental and global climate changes.

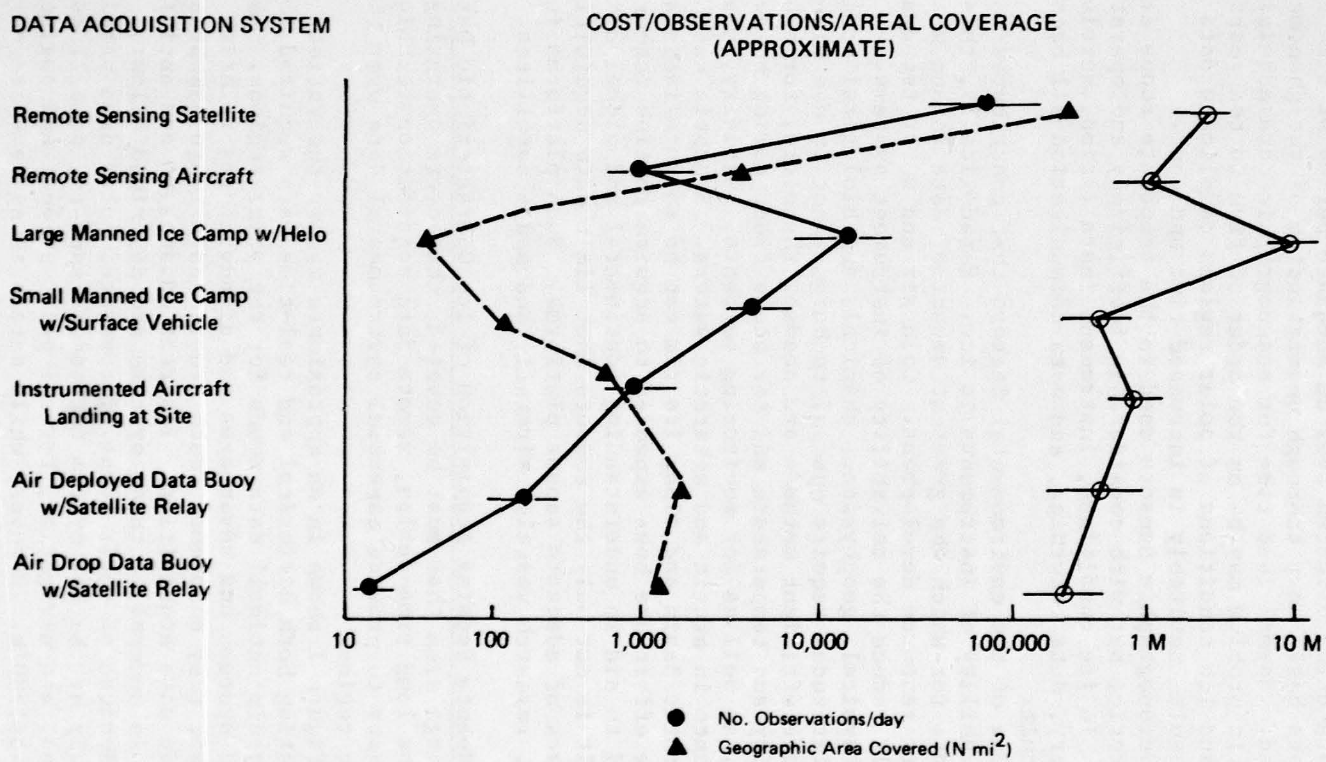
It is not only the sensors that limit data acquisition, but also the lack of adequate sensor platforms. Such platforms include data buoys, research vessels, aircraft, and space satellites.

<u>Remote Sensing Acquisition of Ice Characteristic Data</u> Because of the large area that must be covered, the severe operating conditions, and the long time-scales, remote data acquisition techniques are necessary to provide essential environmental data over the entire arctic region.

Figure I shows in an approximate manner the variety of systems for collecting both historical and real-time data required to provide broadscale national data needs for the polar regions. Each of the listed systems has advantages and disadvantages relative to the others. Even so, they complement each other, and all are essential to comprehensive data acquisition. Inherent advantages and anticipated developments in several of these systems are described below:

Because of their scope of coverage, polar data satellites will probably be the key system for remote sensors, data links, communications, and navigation, for all polar science and engineering work in the mid-1980's. However, while satellite systems are certain to be useful for remote sensing, they alone cannot provide the frequent

FIGURE I



SOURCE: Panel on Polar Ocean Engineering

observations, long time-series, and high resolution necessary to solve certain pressing problems, such as the relationship between driving ice stresses and sea ice response. Moreover, satellite remote sensing systems cannot provide all of the auxiliary information about atmospheric and oceanic variables necessary for the correlation of ice information with other environmental variables.

In the area of aircraft-mounted remote sensing capabilities, fully instrumented flight data and considerable data analysis will be necessary to improve remote imagery interpretation. Significant correlative programs are needed to compare ground measurement, especially of sea ice physical properties, to theoretical models and to remote sensing data in order to eliminate interpretation discrepancies and to increase confidence in the data. Furthermore, sensor testing should be coordinated with ground measurements to assure the continuity of valid sensor performance. Aircraft sensing programs should be of appropriate scope to foster comparisons of seasonal and interannual variations in regions of interest.

In isolated environments, unmanned data systems such as data buoys that can operate unattended and with long lifetimes at low power requirements are expected to be cost-effective. Systems of this type are especially useful in satisfying requirements for high frequency time scales, high data rates, and high spatial resolution. Durable systems must provide links with command functions for calibration checks and switching sensors, and must be capable of performing reliably while unattended for extended periods, because repeated site visits are impractical in the polar oceans. Logistics are complicated by lack of adequate sea ice surface transport, rough areas that make landing conditions difficult for fixed-wind aircraft, and a high incidence of hazardous flying conditions for rotary-wing aircraft.

<u>Arctic Communications and Synoptic Weather Data Acquisition: The Need for a Polar Satellite (POLARSAT) System</u> Although much progress has been made in recent years, obtaining data by remote sensing and from unmanned automatic stations (or "data buoys") in the polar regions is a persistent problem. Point-to-point message communications in the Arctic are also generally unsatisfactory, and in many instances even totally lacking--a situation which is obviously hazardous to individuals or groups on the ice. Application of satellite technology to quantitative studies of the polar regions has remained largely an afterthought, with borrowed or "make-do" adaptations from experiments in more temperate zones of the Earth. Almost no capability exists today for real-time data retrieval, which severely limits operational applications such as providing synoptic weather, ice conditions and movement, and forecasting information. The science and technology required to remedy this problem are largely in existence and could be implemented at an early date.

Specific problems that bear on these general remote-data collecting deficiencies include the following:

- Most satellites do not reach sufficiently high latitudes in their orbit to scan and monitor many interesting and important areas.
- Data outputs are in formats that are difficult to use (uncorrected distortions and unsuitable projections, to cite two problems).
- Voice communications require one or more satellites in or near polar orbit. None is currently available (geostationary comsats are unusable above about 81°N).
- Conflicts with other programs, data delays, expense of data, and other complications expected from the Tiros N/Argos satellite program may limit many arctic applications.
- Because of the lack of high capability (i.e., high data rate) point-to-point satellite radio links, automatic data buoys are presently limited in sensor sophistication and require on-board processing for data compression. Also, this deficiency precludes any commands from manned shore control points for sensor switching, testing, gain changes, calibrations, and so forth, which if available, could greatly increase the usefulness of remote data collection stations.
- There are insufficient ground truth studies and capabilities to verify interpretation of much remote sensing imagery. This is particularly true for passive microwave sensors. A combined program of air and data buoy remote sensing, with both data sets handled through a common system, is not presently possible.

Many experiments, such as those done on ice dynamics and underwater acoustics, require close coordination between multiple, widely removed sites as well as with land bases and aircraft. These data and communications links are necessary for information transmittal from sensors and for transfer of operational, logistic, and emergency information to and from manned, remote observation sites deep in the Arctic Basin. Some of these communications requirements cannot be met without employing satellite technology.

Existing remote sensing hardware is available to provide all-weather monitoring of sea ice conditions. This hardware includes passive microwave radiometers, infrared sensors, synthetic aperture

radar, and radar experimental satellites, such as the Nimbus meteorological series and the now inoperable Seasat oceanographic satellites. However, each of the systems has a finite lifetime that could bring its polar data gathering capability to an early end in the 1980's. An alternative to borrowing the occasional availability of experimental or meteorological satellites is the deployment of a satellite system dedicated specifically to polar services.

A polar satellite system could combine demonstrated capabilities in remote sensing, real-time and data relaying, positioning of platforms, and voice communications that are now absent in the polar regions. Deployment of such a system would facilitate the collection and distribution of economically important arctic data. It could increase real-time data gathering and transmission capabilities which would enhance weather and ice forecasting. Finally, a polar satellite system with voice communications relay capability could increase arctic operational safety and provide the communications capacity that will be necessary to support commercial development.

Technological Improvement of Remote Automatic Data Collection Systems Automatic data buoys, which are an essential tool for gathering polar ocean environmental data, are limited in the data collection tasks they can accurately perform. This is particularly true of air-drop versions used at present to measure atmospheric pressures, ice movements, and air temperatures. While greater sensor sophistication is available in air-deployable systems that are capable of "soft" landings on ice, even these fall far short of manned station data collection capability. Some of the problems include: rime ice formation on sensors, unstable power supplies, poor direction sensing, and solar radiation biasing to temperature sensors. With technical improvements, automatic data buoy systems could routinely perform a great variety of data collection tasks. A new generation of sophisticated data buoys could extend the total data gathering network at sea.

A Ship for Polar Ocean Data Acquisition Development of arctic resources and the need to understand critical polar environmental processes that influence engineering require a broad range of research data. This means that year-round data observations must be made, including sampling and observation in the ice-edge zone and in the thin ice of early winter and broken ice of early spring. Furthermore, engineering and scientific data are needed from the open Bering Sea during winter periods of severe icing. Year-round synoptic data acquisition throughout the polar regions is also required to achieve predictive capability.

Operations in the ice-edge zone, including biological sampling, geophysical surveying, coring, and dredging, require a highly specialized platform, one that is ice-strengthened and that has specialized devices and facilities for data acquisition in ice conditions. While U.S. Coast Guard icebreakers are, to some degree,

available for surveys and sampling, they are usually dedicated to other more urgent missions and are ill-suited for specialized research such as geophysical, geological, and biological sampling.

The utility of a vessel designed specifically for polar research has been recognized by other nations. The Soviet Union has recently completed design studies for a conventionally-powered, ice-strengthened polar research vessel capable of operating in ice leads. The Federal Republic of Germany has initiated design studies for an ice-strengthened research vessel for use primarily in gathering information on antarctic energy resources. For some years, Japan has maintained and operated an icebreaker with research capability for research purposes. This vessel's operations have centered on the Antarctic.

Without suitable polar research vessels, other more costly data acquisition platforms will be needed, thus reducing the amount of research done with available funds. Although a specially designed vessel is the first choice of the research community, possible alternative research platforms include submarines, surface effect vehicles, and conversion of existing ships, such as "wind-class" icebreakers, which are scheduled to be decommissioned in a few years. However, the expense of converting existing ships and the cost of any possible alternatives are high, and the results may be less than satisfactory.

The panel concludes that:

- Polar ocean data acquisition systems require major improvements in sensors, platform availability, and communications.

- Primary deficiencies or inadequacies in polar ocean data acquisition include:

  - Remote sensing capability and space satellite sensor platforms;

  - Remote automatic oceanographic data collection systems for ice covered or ice infested areas;

  - Adequate offshore-to-shore data and operations communications link and;

  - Availability of an adequate ship platform for ocean data acquisition in the marginal ice zones.

Therefore, THE PANEL RECOMMENDS THAT:

IMPROVED REMOTE SENSING CAPABILITY BE DEVELOPED, ESPECIALLY FOR CHARACTERIZING ICE.

A program to improve remote sensing capabilities to characterize the regional ice environment should include experimental flights to prove or develop sensors, combined with ground-truth sensor measurements and theoretical modeling efforts to delineate and evaluate sensor performance. A simultaneous and integrated effort should be started to improve and expand related data processing techniques with emphasis on quality, timeliness, availability of data, and cost.

The program should include developing and testing air drop buoys capable of accurate air temperature and wind velocity measurements; deploying sensors beneath the ice (e.g., thermistor strings, current meters, and hydrophones); and include self-calibration capability with accurate measurement of the following: air velocity; orientation relative to true North; water current velocity; precise self navigation; ice thickness growth; bathymetry; gravity; magnetics, radio frequency and acoustic propagation; water salinity and temperature profiles; air and surface temperature; and humidity. Technical development objectives include: eliminating riming on moving sensors, possibly through heating; developing better cold weather, long-life power sources (e.g., wind generators, solar panels, water current generators, and heat-differential generators); and improving direction sensors by using improved magnetic compasses, radio, sun finders, or magnetodiodes.

Therefore, THE PANEL RECOMMENDS THAT:

POLAR BUOY SYSTEMS BE IMPROVED FOR THE COLLECTION OF OCEANOGRAPHIC DATA AND FOR THE COLLECTION OF METEOROLOGICAL DATA.

Thus, improved data collecting techniques should be developed to advance operational forecasting of weather and ice conditions in arctic offshore waters, thereby enhancing safety and efficiency of offshore operations. This should include the test deployment of an array of data buoys to acquire ice drift and meteorological data throughout the Arctic Ocean. The data buoy program should be conducted as an international effort, involving the U.S. and Canada, and possibly other circumpolar nations. During 1978, as part of the First Global Experiment of the Global Atmospheric Research Program, (GARP), an array of 20 data buoys, powered for a year at sea, were air dropped. The performance of this array needs to be evaluated, improved as necessary, and replaced or redeployed for an indefinite period to obtain further operational experience as well as data. To service this system, a real-time data readout capability should be instituted, possibly through the Tiros-N satellite system.

Accordingly, THE PANEL RECOMMENDS THAT:

A STUDY BE CONDUCTED OF THE ESSENTIAL FEATURES OF A POLAR ORBITING SATELLITE SYSTEM. THE SYSTEM SHOULD ALSO PROVIDE FOR COMMUNICATIONS NEEDS IN THE HIGH POLAR REGIONS.

These needs would include but not be limited to:

- All-weather remote sensing of sea ice conditions necessary for large-scale ice monitoring and forecasting purposes, using passive and active radar systems.

- Delayed data relay channels with in-satellite capability to provide surface platform positions, such as the Random Access Measuring System used on Nimbus-6.

- Near real-time, high capacity, and multi-channel point-to-point data relay with command functions.

- Voice channel relay capability to alleviate interference from highly variable ionospheric conditions or limitations to line-of-sight distances in remote manned operations.

The specific capability of the satellite should be determined by users in offshore industries, ocean science, and government agencies. Such a satellite system would provide service to both polar regions on a nearly continuous basis.

THE PANEL RECOMMENDS THAT:

AN ARCTIC MARGINAL-ICE-ZONE-COMPATIBLE SHIP BE DESIGNED AND MADE AVAILABLE FOR ACADEMIC, GOVERNMENT, AND INDUSTRIAL USE FOR THE ACQUISITION OF POLAR OCEAN ENGINEERING DATA AND THE CONDUCT OF SCIENTIFIC RESEARCH AND DEVELOPMENT PROGRAMS.

Logistics for various modes of polar data acquisition need to be evaluated.

The polar research ship design study funded by the National Science Foundation should continue to solicit advisory contributions from the national scientific and engineering communities. Recently completed, the first phase of this study produced a conceptual design for general purpose national research ships for the Arctic and the Antarctic.[5] Further development in the form of a more detailed design study, including design specifications and hull model testing in ice model tanks, now needs to be undertaken. Polar ocean engineering requirements should be taken into consideration. Finally, one or two polar oceanographic ships should be developed, constructed, and made available as soon as possible for both arctic and antarctic investigations.

Interactions Between Engineered Systems and the Environment

The stressful environment of the polar regions severely limits structural design parameters. Moreover, the physical and biological environment may be changed or modified by the structure. Therefore, it is essential that engineered systems be designed, fabricated, and operated with an understanding and sensitivity to potential impacts on the environment. If the mineral resources of the Arctic Ocean are tapped, the environmental impacts concerns are likely to include: effects of oil, muds, and cuttings on various arctic biota; effects of intense cold on the spreading, aging, and biodegradation of oil spills; movement of oil beneath, between, and in ice under different ice conditions; and effects of oil spill cleanup methods, such as the use of dispersants or in-situ burning of spilled oil. Moreover, excavations, dredging, artificial islands, causeways, piers, and other structures may have effects on shoreline erosion and sediment transfer that require analysis on a site-specific basis.

Numerous studies concerned with the "fate and effect" of oil spills in arctic waters have already been performed in Canada under the Beaufort Sea and Arctic Marine Oil Spill Program. Studies of releases of oil, muds, and cuttings in temperate waters may also be applicable to the Arctic. Although laboratory research may provide additional insights, the most realistic understanding of these problems is obtained through field experiments.

Natural shoreline processes and man-made alterations have been studied extensively outside the Arctic. The findings of such studies may be used as a basis for assessing the environmental effects of coastal engineering activities in the Arctic. Even so, quantitative and qualitative uncertainties exist because of certain differences between the arctic and temperate nearshore environments. The Arctic is characterized by: a possibly slower rate of recovery from severe biological disturbance; reduced wave action during periods of ice cover --hence, lower rates of coastal erosion and dispersion of pollutants; and general absence of industrial pollutants in arctic sea floor sediments. The implications of such differences on polar ocean facilities need to be examined in a timely way through field studies of offshore exploration and development operations.

In addition, a large body of oceanographic data, including measurements of chemical, biological, geological, and other environmental parameters such as data on sediment strength and composition, heavy metal trace elements, dissolved oxygen, and hydrocarbon content has been amassed for the Arctic through the U.S. Bureau of Land Management. Selected parts of these data will be useful to offshore resource development engineers.

<u>Fate and Effect of Oil, Muds, and Cuttings</u> A better understanding of the fate and effect of oil, muds, and cuttings released in arctic waters is required to properly assess the impact of these materials on the offshore arctic environment. Field testing to determine the fate

of potentially hazardous chemicals and byproducts are necessary to properly assess the environmental effects of recovering polar resources. The information gained from such tests can be collected to form the data base for informed, cost-effective government regulation of operations. Field test information would also contribute to a number of technical engineering matters, including the development of detection capability for remote oil spills, verification of predictive models of oil spill behavior, and development of efficient, cost-effective oil spill containment and cleanup systems.

Environmental Baseline Surveys: Data Interpretation for Polar Ocean Engineering Use Many of the ecological and environmental considerations that need to be considered in the development of arctic offshore resources are similar to those that have been addressed in other regions. However, factors unique to polar regions must also be considered. A large quantity of data on some of these factors has been collected by the Bureau of Land Management's Outer Continental Shelf Environmental Assessment Program. Unfortunately, little of the data has been analyzed or interpreted in relation to offshore development activities. The baseline data already collected can be used to resolve uncertainties in polar ocean engineering design criteria related to protecting the ecosystem, provided the data are interpreted and presented in a manner that is relevant to ocean engineering.

In light of this, the panel concludes that advances in the state of knowledge and practice of polar ocean engineering may have significant effects on polar environment. Thus, attention should be directed to dealing with:

- Insufficient knowledge of the fate and effect of oil, muds, and cuttings in arctic waters; and,
- Uncertainties about the effects of offshore resource development on arctic ecosystems.

Therefore, THE PANEL RECOMMENDS THAT:

- FIELD STUDIES BE CONDUCTED TO DETERMINE THE EFFECT OF AN OIL SPILL ON LANDFAST ICE. THE LONG-TERM EFFECTS OF OIL, DISPERSANTS, AND BURNING IN ICE-COVERED WATERS NEED TO BE ASSESSED. THE ENVIRONMENTAL IMPACT OF THE DISPOSAL OF DRILLING MUDS AND CUTTINGS IN ARCTIC WATERS SHOULD BE DETERMINED.

It is recommended that a controlled oil spill testing program be undertaken at an early date in the landfast ice area of the Beaufort

Sea. This will require a multidisciplinary approach, with the participation of scientists from government, academe, and industry.

The effects of oil, dispersants, and the residue from burning on arctic biota need to be monitored for several years in order to assess the long-term implications for the food chain. The tests should be coordinated with studies on remote oil spill detection, containment, and cleanup.

A joint industry-government field program should be initiated to assess the environmental impacts of disposing of drilling muds and cuttings in arctic waters. Such a program is most likely to be successful if run in conjunction with an actual offshore drilling operation and if coordinated with studies of remote oil spill detection, oil spill containment, and cleanup. The results of previous studies, including field tests in Canada on the fate and effect of oil, muds, and cuttings, should be used in the planning and execution of the proposed programs.

THE PANEL RECOMMENDS THAT:

DATA ACQUIRED BY THE BUREAU OF LAND MANAGEMENT (BLM) FOR THE DEPARTMENT OF INTERIOR'S OUTER CONTINENTAL SHELF ENVIRONMENTAL ASSESSMENT PROGRAM (OCSEAP) BE ANALYZED AND MADE AVAILABLE FOR USE IN THE ESTABLISHMENT OF ENGINEERING DESIGN CRITERIA.

So that the data presently available only in tabular form or in some uninterpreted format might be made directly useful to the ocean resource development engineer, the panel proposed the following action to implement its recommendations:

An interdisciplinary task force of marine scientists, engineers, and administrators from academe, industry, and government should undertake a review of the collected BLM OCSEAP data to identify that part of the data which, if analyzed, would:

1) Significantly reduce the ecological uncertainties related to offshore development; and,

2) Aid in establishing ecologically related engineering criteria for design, construction, and operation of offshore facilities.

Identified data should be analyzed with interdisciplinary goals set in order to provide evaluations that address significant long-term changes and the vulnerability of the ecosystem to man's polar activities.

Polar Ocean Logistics

The supply, movement, and support of operations, which are known as logistics when considered as a total system, become a limiting factor on offshore engineering and scientific objectives in polar regions. Logistics include people, supplies, and heavy equipment deployed to support assessment, exploration, and development. In the Arctic, significant increases in logistics are required to support offshore pipelaying, artificial islands, and other structures constructed for oil drilling and production operations, as well as to support the transportation necessary to ship petroleum, minerals, and living resources to market. Adequate logistics are as essential to scientific endeavors in the polar oceans as to commercial ones. Logistical support needs for both kinds of activities in the polar environment are discussed below.

Medium-Range Air Logistic Capability To gain ready access to remote offshore areas, aircraft are required with capabilities for withstanding the severe polar weather conditions and for landing and taking off on largely unimproved snow and ice surfaces. Clearly, then, pilots need to be able to assess the adequacy of the surfaces at the time of approach.

Extending scientific research and resource exploration operations into central arctic regions such as the Eurasian Basin is constrained by the inability of medium- and long-range aircraft to land on unprepared ice. Without such capability, the establishment and supply of camps any distance away from such centers as Barrow, Alaska, becomes extremely difficult. U.S. arctic operations have been largely limited to a small radius of action around the primary support base at Barrow, because no suitable aircraft have been available with short take-off and landing (STOL) and significant cargo carrying capabilities. In the past, long and thick refrozen leads have been required for landing large aircraft on the pack ice. Such leads are difficult to find, however, and they must first be surveyed by a ground party. Moreover, they tend to last for only a limited time. Small STOL aircraft, capable of landing directly on rough multi-year floes, have not had sufficient range or cargo capabilities for air logistical capability to support operations into the ice-covered central Arctic Ocean.

At present, several conventional aircraft are being modified to meet the need for a medium-size, longer-range, STOL aircraft designed for rough landings. The modified aircraft will require testing and evaluation. Because aircraft development costs are high and the use of medium-range aircraft, though important, remains limited, aircraft needs for the Arctic continue to be met by existing aircraft that are modified for the polar areas. The development of suitable polar aircraft would extend the logistical capability of research teams into the central Arctic and the Eurasian Basin. The detailed knowledge gained as a result of such capability would greatly enhance the future development of the polar regions.

Helicopters--Ice Prevention and De-Icing Techniques Helicopters are used extensively in short range polar logistics. They are the principal craft used by the Coast Guard for search and rescue operations off the decks of icebreakers. However, helicopters are handicapped by icing of their rotors and airframes, as well as by white-out conditions. Such problems are serious to helicopters because icing is most commonly encountered during the arctic summer, when surface conditions limit the use of more conventional support aircraft in ice-related research, exploration, and development. This is also the period when shipping, and helicopter-equipped Coast Guard icebreaking operations are most active. Although icing is the major limitation on the extensive use of helicopters in polar regions, little research has been conducted to overcome the problem.

Sea Ice Surface Vehicles Engineers and scientists working offshore usually require the ability to move around the local area. The need to establish and operate seismic or oceanographic stations at great distace from logistical centers and in the midst of hummocks, leads, ice of various thickness and age, and sometimes white-out conditions points to the need for a vehicle or family of vehicles not restricted by environmental conditions. Surface mobility in the arctic pack ice can be critical to the conduct of scientific research and resource exploration and development. Surface vehicles are needed to provide over-the-ice and through-leads mobility. Accordingly, they will range from small "pick-up truck" vehicles to personnel carriers to cargo transporters with "tractor-trailer" capabilities.

The radius of mobility required is approximately 80 km around remote stations. While helicopters can provide many services within their relatively short range from a shore base, polar operations planned for the 1980's will include programs at remote stations outside today's helicopter ferrying range. The alternatives are to disassemble a helicopter and fly it out in large fixed-wing aircraft or to establish a system of fuel caches, which involve logistical difficulties, human hazards, and high costs.

Helicopters not only require large quantities of fuel and highly qualified operators but also are difficult to maintain on ice. The use of fixed-wing aircraft requires a long, prepared landing strip with its associated high costs and long construction period. A more cost-effective approach to mobility in pack ice is likely to be specially designed surface vehicles. A family of such vehicles would have many uses--from support for scientific research and logistics of nearshore petroleum operations, particularly in areas of rough ice or during periods when ice is freezing or breaking up, to oil spill cleanup operations in pack ice. Sea ice surface vehicles could also improve the current state of arctic search and rescue operations. A particular advantage of a surface vehicle is its capability to operate in bad weather compared with the extreme vulnerability of aircraft, especially helicopters, in near-surface conditions such as white-outs and gales.

In the development of logistic support vehicles, the panel is unaware of any comprehensive studies underway to develop the suggested fleet of personnel and equipment support vehicles needed for over-ice

operations, including search and rescue activities. Assessments of certain relevant technologies, such as air-cushion vehicles, have been conducted. A comprehensive examination of the matter would complement such studies.

Improved Logistics for Small Offshore Camps Polar field operations are often limited by logistical problems arising from the difficulty and expense of conducting operations under harsh conditions. Improving logistical support in this context would include more appropriate designs for energy supply systems, communications, and housing at offshore installations maintained on drifting ice.

A significant portion of the total arctic research budget goes to the supply of fuel for transportation of personnel and scientific apparatus and "hotel services" to support base camps and field investigations. Significant savings in the cost of these logistical services through better design, for instance, or improved communications, could be applied directly to research.

Small Power Sources for Remote Polar Operations Meeting the need for basic power and, if possible, energy self-sufficiency at scientific and commercial bases, field camps, and remote instrumentation sites in polar regions is a continuing problem that is not easily solved. In some cases, the costs and problems of meeting power needs are so prohibitive that operations have to be curtailed. Conventional energy systems rely on petroleum, causing major difficulties in transporting and storing fuel. Some unconventional power sources are subject to stringent regulatory requirements that may preclude their deployment at remote unmanned sea ice sites. For example, regulations on the use of radioisotope generators call for the continuous inspection or monitoring of the power site and eventual removal of the generator. Unmanned instrumentation could provide more data if it were not as limited by electrical power constraints as it is at present.

On the basis of these findings, the panel concludes that:

- Inadequate logistics continue to severely constrain polar offshore engineering and scientific operations.

- Particular deficiencies include:

  - Inadequate offshore ice surface logistics transport;

  - Medium-range logistic capability;

  - Icing prevention and de-icing techniques for helicopters;

  - General logistics associated with offshore installations; and,

- Reliable power sources for remote polar operations.

Therefore, THE PANEL RECOMMENDS THAT:

REQUIREMENTS AND ENGINEERING CONCEPTS BE DEFINED FOR A FAMILY OF SEA ICE SURFACE UTILITY VEHICLES FOR TRANSPORT OF PERSONNEL AND SUPPORT EQUIPMENT.

Performance criteria for such sea ice surface vehicles should include the capability for near straight-line 80 km traverses of the arctic pack ice and for negotiating nearly flat ice or floes, thin ice of refrozen leads, open smooth water of leads and polynyas, and pressure ridges.

Because vehicles are not expected to be capable of traveling independently from shore to remote work locations up to 800 or 1,000 nautical miles from the logistics base, the vehicles need to be modular units that can be carried by aircraft that can land on unprepared and unmarked ice floes. An example of such an airplane is the Tri-Turbo-Three, a three turboprop version of the C-47.

Sea ice surface vehicles must be equipped with precise navigation equipment to be used in conjunction with resource exploration and scientific work, full-time radio communications gear, and radio direction finders for locating air-dropped fuel and food caches, as well as for relocating remote unmanned data stations. The operation of vehicles would have to be coordinated under such circumstances with fixed-wing aircraft for support.

Because of the uniqueness of the requirements, the variety of field conditions encountered, and the range of potential applications, it is probable that more than one configuration for sea ice surface vehicles is desirable for field feasibility tests.

Therefore, THE PANEL RECOMMENDS THAT:

ADDITIONAL RESEARCH EFFORT BE DIRECTED TO IMPROVING LOGISTICAL SUPPORT FOR ENGINEERING AND ARCTIC OPERATIONS. THE PURPOSE OF THE EFFORT IS TO IMPROVE MEDIUM-RANGE AIR LOGISTICS SUPPORT OF OFFSHORE SCIENTIFIC SITES; REDUCE ICING SUSCEPTIBILITY OF HELICOPTERS USED FOR SEARCH AND RESCUE AS WELL AS FOR LOGISTICS; DEVELOP EFFICIENT COLD REGION ENERGY SOURCES: AND GENERALLY ADVANCE REMOTE SITE LOGISTICS.

In meeting the requirements of medium-range air logistics capability, if the 1979 tests and evaluations of the DHC-7 and the Tri-Turbo-Three aircraft show that the need still exists for a serviceable medium-range arctic aircraft, other existing airframes should be investigated. To deal with the problem of helicopter icing, a review of helicopter icing and de-icing should be undertaken by the U.S. Coast

Guard in cooperation with the U.S. Navy and in consultation with helicopter manufacturers in order to arrive at possible solutions.

A comprehensive review also should be undertaken of the logistical requirements of small offshore camps. The review should cover technical and equipment requirements. It also should identify possible areas for cooperation between the government and the private sector in meeting the logistical needs to consolidate requirements and cut costs. Studies should include field tests of equipment, supplies, and consolidated logistical systems.

Finally, a program should be undertaken to develop and field test alternative power sources and energy storage techniques, including:

- Energy derived from the natural environment --for example, from wind, solar, temperature gradient, ocean currents, and waves;

- Exogenous sources--fuel cells and batteries suited to polar applications, for instance; and

- Conservation--including more efficient construction techniques, dual use of energy for equipment power and space heat, reduction of energy required for human operation by making operations automatic, and making better use of advanced low-power electronics.

NON-TECHNICAL CONSTRAINTS ON THE GROWTH OF POLAR OCEAN ENGINEERING

Several nontechnical matters gained importance in the course of the panel's considerations of technological deficiencies in polar ocean engineering. While ancillary to the panel's main work, the technical ramifications of the nontechnical constraints on the growth and vitality of polar ocean engineering are deemed of sufficient scope to warrant attention.

Accordingly, it is clear to the panel that engineering activities vital to polar resource development may be hindered, delayed, or totally blocked by unresolved institutional questions. Laws and treaties need to be framed to promote and maintain the social, scientific, economic, and other interests of the U.S. Such interests are tied directly to the ability to enhance the quality of life of arctic residents, to promote resource recovery and national security in the Arctic, and to conduct economic resource recovery operations in the future in the Antarctic. The polar ocean engineering, commercial, and scientific communities need to take the initiative in identifying issues and institutional factors that will promote, not retard, the enhancement of the quality of life of the human inhabitants of the Arctic and the scientific activity and resource development by the U.S. in the polar zones.

In order to resolve some of the institutional issues that have potential to retard resource development and scientific activities in the polar oceans, the panel recommends that:

- Outer continental shelf (OCS) leases need to be made consistent with the time periods required to install drilling and production equipment in the polar environment, as well as with the risk assessment of the lease;

- Data gained from such other offshore operations as dredging should be used to assist in evaluating related OCS operations in the polar regions, such as the discharge of uncontaminated drilling mud and cuttings into the sea; and

- Future treaty arrangements related to antarctic krill should provide for resource management controls prior to commercial exploitation, because the technical task of determining the optimum sustainable yield of the krill harvest will be central to its management.

Many recommended polar research and development programs, especially those that include the collection of synoptic data, would be more effectively planned and implemented with international cooperation. Throughout this report, relevant international efforts have been noted wherever appropriate. Under the 1959 Antarctic Treaty, international approaches to scientific research and development have been common in Antarctica.[6] Similar international approaches are particularly appropriate in the Arctic, where the trend toward the extension and assertion of sovereignties raises genuine concerns, not the least of which is the acquisition of synoptic data. For example, international cooperation in the development of remote sensing systems, including possibly the ownership and operation of a polar-orbiting satellite by a group of nations, is an initiative that could result in useful and dependable systems at the lowest cost and would serve the best interests of the U.S. and the rest of the world.

As the U.S. grows more deeply committed to scientific and technological activities in polar regions, the need for highly competent polar ocean engineers and scientists will increase. While classical meteorology and oceanography apply to polar regions in the same way that classical engineering and fluid mechanics apply, it is important to address those many unique and complex problems of solid-state oceanography and low temperature mechanics.

There is a paucity of cold regions engineering courses available in the nation's engineering schools. Too often low-latitude technology has been simply forced to fit the conditions of polar regions, with unsatisfactory results. The lack of people with academic training in cold regions and ocean engineering specialization retards understanding and development of the the polar regions and hinders the growth of innovative cold regions technologies. Thus, the need exists to expand and encourage the study of cold regions engineering problems in institutions of higher education that are both committed and competent to conduct such programs. Post-graduate curricula in cold regions marine engineering also needs to be developed.

In the polar regions, high costs, severe environmental conditions, and logistical difficulties make the coordination of programs and activities within the government and between government and industry especially important. Until recently, the technical, scientific, and engineering aspects of government polar research programs had been coordinated through the Interagency Arctic Research Coordinating Committee (IARCC). Since the IARCC was dissolved in 1978, no U.S. organization has been central to all polar technology, including engineering, although the National Science Foundation has continued to sponsor and coordinate antarctic research.

The panel finds that both the challenge and the opportunity now exist to provide a stronger polar ocean coordinating organization for governments. Such an organization could provide an important linkage with academe and industry. One prospect of such a coordinated effort could be the establishment of a clearinghouse to promote the documentation, transfer, and exchange of technical information on polar ocean engineering. It is a dilemma that the lack of a comprehensive approach

to polar information management and technology transfer makes coordination more difficult among government, academe, and industry.

Accordingly, THE PANEL RECOMMENDS THAT:

AN APPROPRIATE ORGANIZATION AND INSTITUTION BE IDENTIFIED OR ESTABLISHED TO SERVE AS THE GOVERNMENT FOCAL POINT FOR IDENTIFYING, RECOMMENDING, AND COORDINATING SOLUTIONS TO NONTECHNICAL, NONSCIENTIFIC CONSTRAINTS ON POLAR RESOURCE DEVELOPMENT.

NOTES

1. Hudson, Travis, and John D. DeYoung, Jr., "Map and Tables Describing Areas of Mineral Resource Potential, Seward Peninsula, Alaska," U.S. Geological Survey Open File Report 78-1-C, Menlo Park, California, 1978. Also, "Map and Tables Describing Mineral Resource Potential of the Brooks Range, Alaska," U.S. Geological Survey Open File Report 78-1-B, Menlo Park, California, 1978.

2. Report of the Ninth Antarctic Treaty Consultation Meeting, London, 8 December, 1977.

3. Code of Safety for Fishermen and Fishing Vessels, Inter-Governmental Maritime Consultative Organization, London, no date.

4. Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS) Vol. I - Research Proposals, Scientific Committee on Antarctic Research, International Oceanographic Commission, August, 1977.

5. Polar Research Vessel: A Conceptual Design, Robert Elsner et al., University of Alaska, Fairbanks, Alaska, 1977.

6. The Antarctic Treaty (12 UST 794-800).

BIBLIOGRAPHY

The following list of publications were compiled for the use of the panel in the course of the study.

Alaska Oil & Gas Association. 1975 Status of Arctic Research Requirements for Oil and Gas Operations in the Alaskan Arctic. Alaska Oil & Gas Association, Anchorage, Alaska, December 1976.

______________________________. "Comments on OCSEAP Special Bulletin No. 15, Beaufort Sea Synthesis Report." Alaska Oil & Gas Association, Anchorage, Alaska. No Date.

Amario, P. J. and Bauneau, A. A., eds. Arctic Systems. Proceedings of a NATO Conference held at Memorial University of Newfoundland, August 18-22, 1975. Memorial University of Newfoundland, St. John's, Newfoundland, Canada, 1977.

Arctic Institute of North America. Northern Research Survey. Arctic Institute of North America, Calgary, Alberta, Canada, March 1976.

______________________________. Northern Research Survey. Arctic Institute of North America, Calgary, Alberta, Canada, July 1976.

Barnes, Farrel F. "Coal Resources of Alaska." Bulletin 1242-B, U.S. Geological Survey, Washington, D.C., 1967.

Buck, B. M. "Brief Comments on Problems of and Potentials for Arctic Communications." Unpublished presentation to the Marine Board, December 1977.

Cary, K. L., Ashton, G. D., and Frankenstein, G. E. Ice Engineering for Civil Works Baseline Study. Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, August 1973.

Clarke, M. L., Durfee, D. W., and Shaw, S. H. Arctic Adapts Engineering Analysis, Prototype Development and Testing, Vols. 1 and 2, Seaward International, Inc., Falls Church, Virginia, 1976.

Clautice, W. G. and Sheets, H. C. "Submarine Tanker Navigation in the Arctic." Marine Technology Society Journal, Vol. 8, No. 8, pp. 29-37, September 1974.

Croasdale, K. R. "Ice Engineering for Offshore Petroleum Exploration in Canada." Proceedings of the Third International Conference on Port and Ocean Engineering under Arctic Conditions. Institute of Marine Science, University of Alaska, Fairbanks, Alaska, 1976.

DeFong, J. J., Stigter, C., and Steyn, B. "Design and Building of Temporary Artificial Islands in the Beaufort Sea." Proceedings of the Third International Conference on Port and Ocean Engineering under Arctic Conditions. Institute of Marine Science, University of Alaska, Fairbanks, Alaska, 1976.

Dome Petroleum, Ltd. Marine Delivery Systems for Alaska Offshore Oil and Gas. Dome Petroleum, Ltd., Calgary, Alberta, Canada, January 1978.

Eggington, W. J. and George, D. B. "Application of Air Cushion Technology to Offshore Drilling Operation in the Arctic." Proceedings of the Offshore Technology Conference. Paper No. 1165. Offshore Technology Conference, Dallas, Texas, 1979.

Gow, A. J. and Weeks, W. F. The Internal Structure of Fast Ice Near Narwhal Island, Beaufort Sea, Alaska. CRREL Report 77-29. Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, 1977.

Husseiny, A. A. "Iceberg Utilization." Proceedings of the First International Conference on Iceberg Utilization. Pergamon Press, New York, N.Y., 1977.

Ives, M. B., ed. Materials Engineering in the Arctic. Proceedings of an International Conference, St. Lovite, Quebec, Canada, September 27-October 1, 1976. American Association for Metals, Metals Park, Ohio, May 1977.

Jenkins, Wallace T. A Guide to Polar Diving. Naval Coastal System Laboratory, Panama City, Florida, June 1976.

Karlson, Thorbjorn, ed. Proceedings of an International Conference on Sea Ice, Reykjavik, Iceland, May 10-13, 1971. National Research Council, Reykjavik, Iceland, 1972.

Kingery, W. D., ed. Ice and Snow Properties, Processes and Applications. Proceedings of a Conference held at the Massachusetts Institute of Technology, February 12-16, 1962. MIT Press, Cambridge, Mass., 1963.

Major, R. A., Gulick, R. W., and Calabese, S. J. "Abrasion Resistant Coatings and their Application to Ice Transiting Ships." Presentation to Chesapeake Section of the Society of Naval Architects and Marine Engineers, February 16, 1978.

Mookhoek, A. D. and Bielstein, W. J. "Problems Associated with the Design of an Arctic Marine Transportation System." Proceedings, 1972 Offshore Technology Conference. Offshore Technology Conference, Dallas, Texas, 1972.

Muggeridge, D. B., ed. Proceedings of the Fourth International Conference on Port and Ocean Engineering under Arctic Conditions, September 26-30, 1977. Memorial University of Newfoundland, St. John's, Newfoundland, Canada, 1978.

National Advisory Committee on Oceans and Atmosphere. Seventh Annual Report. A Summary of NACOA Recommendations, January - June 1978. National Advisory Committee on Oceans and Atmosphere, Washington, D.C., June 1978.

National Research Council. Polar Research, A Survey. Committee on Polar Research, National Academy of Sciences, Washington, D.C., 1970.

________________________. An Evaluation of Arctic Programs Supported by the National Science Foundation. Polar Research Board, Assembly of Mathematical and Physical Sciences, National Academy of Sciences, Washington, D.C., 1977.

________________________. Problems and Priorities in Offshore Permafrost Research. Polar Research Board, Assembly of Mathematical and Physical Sciences, National Academy of Sciences, Washington, D.C., 1978.

________________________. Report on United States Antarctic Research Activities Planned for 1978-79. Polar Research Board, Assembly of Mathematical and Physical Sciences, National Academy of Sciences, Washington, D.C., 1978.

________________________. Marine Systems in Frigid Environments, Special Bibliography. Maritime Transportation Research Board Research Information Service, National Academy of Sciences, March 1978.

National Science Foundation. Arctic Research. Arctic Bulletin, Vol. 2, No. 11. Interagency Arctic Research Coordinating Committee, National Science Foundation, Washington, D.C., 1977.

NORCOR Engineering and Research, Ltd. A Study of Ice Conditions Along Marine Shipping Routes in the Arctic Archipelago. NORCOR Engineering and Research, Ltd., Yellowknife, Northwest Territory, Canada, March 1978.

Schwarz, J. and Weeks, W. F. "Engineering Properties of Sea Ice." Journal of Glaciology, Vol. 19, No. 81, pp. 499-531. International Glaciological Society, Cambridge, England, 1977.

Scientific Committee on Antarctic Research. "A Preliminary Assessment of the Environmental Impact of Mineral Exploration/Exploitation in Antarctica." Scientific Committee on Antarctic Research, University Library, Cambridge, England, 1977.

Trye, Pen. Intermittant Ice Forces Acting on Inclined Wedges. CRREL Report 77-26. Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, October 1977.

University of Alaska. Proceedings of the Third International Conference on Port and Ocean Engineering under Arctic Conditions. Institute of Marine Science, University of Alaska, Fairbanks, Alaska, 1976.

_________________. OCSEAP Beaufort Sea Synthesis Report. Special Report No. 15. Arctic OCS Program Office, Geophysics Institute, University of Alaska, Fairbanks, Alaska, June 1, 1977.

_________________. Current Research Profile for Alaska. Arctic Environmental Information Center, University of Alaska, Anchorage, Alaska, 1978.

University of Washington. Arctic Data Buoy and Positioning Systems, AIDJEX Bulletin No. 7. Arctic Ice Dynamics Joint Experiment, Division of Marine Resources, University of Washington, Seattle, Washington, April 1971.

U. S. Department of the Army. Demonstration Program Report. Great Lakes - St. Lawrence Seaway Winter Navigation Board, U. S. Corps of Engineers, Department of the Army, Washington, D.C., 1978.

U. S. Department of Commerce. National Program for Continuing Environmental Monitoring for the Marine Leg of the Trans-Alaska Pipeline System. Interagency Committee for Marine Environmental Prediction, National Oceanic and Atmospheric Administration, Department of Commerce, Rockville, Maryland, October 1973.

_____________________. Environmental Assessment of the Alaskan Continental Shelf April 1976 - March 1977. Outer Continental Shelf Environmental Assessment Program Office, National Oceanic and Atmospheric Administration, U. S. Department of Commerce, Boulder, Colorado, 1977.

____________________________. Interim Synthesis Beaufort/Chukchi Seas. Outer Continental Shelf Environmental Assessment Program Office, National Oceanic and Atmospheric Administration, Department of Commerce, Boulder, Colorado, August, 1978.

U. S. Department of Interior. Mapping: An Annual Report of USGS Cartographic Research. Topographic Division, U.S. Geological Survey, Department of Interior, Washington, D.C., 1976.

U. S. Department of the Navy. Naval Research Reviews, May 1976. Office of Naval Research, Department of the Navy, Arlington, Virginia, May 1976.

U. S. Department of Transportation. Polar Transportation Requirements Study Report. U. S. Coast Guard, Department of Transportation, Washington, D. C., November 1, 1968.

World Meteorological Organization. The Polar Sub-Programme. Global Atmosphere Research Programme, World Meteorological Organization, Geneva, Switzerland, 1978.

APPENDIX A

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POLAR OCEAN ENGINEERING WORKSHOP HELD AT CRREL,
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APPENDIX B

FEDERAL AGENCY CONCERNS IN POLAR REGIONS

Many federal agencies listed and discussed below, have responsibilities for supporting polar ocean activities.

National Science Foundation (NSF).

The National Science Foundation's Division of Polar Programs has the lead role for conducting scientific investigations in the Antarctic. A wide range of ocean science is supported, including physical oceanography of antarctic circulation and sediment coring programs in the Ross Sea. Signed in December 1959, the Antarctic Treaty, effective for 30 years, prohibits military activity in the area and stresses the peaceful use of the continent. The issue of exploitation of natural resources has been under discussion during treaty renewal negotiations. The resources would include oil and gas, hard minerals, and perhaps ice. NSF also sponsors the Biomass program effort, which is directed toward investigating antarctic krill as a protein source.

In the arctic region, NSF is the lead agency for the extension of federal research in the area. Research objectives include:

1. Study of the polar pack ice and its relationship to transportation, global weather, sedimentation processes, and coastal ecology.

2. Study of the polar magnetic field and its effect on electronic communications.

3. Investigation of the geologic structures underlying the seas.

4. Developing an understanding of the arctic ecosystem.

5. Studies of liquid and solid waste disposal in the Arctic.

6. Assessment of human capabilities to adapt to the inhospitable polar environment.

AIDJEX - One recent important marine experimental program funded by NSF's Division of Polar Programs was the Arctic Ice Dynamics Joint Experiment (AIDJEX), a combined theoretical and field study of the dynamics and thermodynamics of sea ice. The goal of the study is to develop a predictive model of ice deformation in response to atmospheric and oceanographic forces. The information provided by the AIDJEX model is likely to help solve such other problems as ice cover interactions with global atmospheric circulation and assessment of ship-ice interaction forces.

The AIDJEX main experiment began in March 1975 and ended in May 1976. Four manned stations were deployed on the ice of the Beaufort Sea, about 640 km north of Barrow, Alaska. In October 1975, ice cracks and pressure ridges forced abandonment of Big Bear, the main camp, but the field program continued with a three-station array (Caribou, Snow Bird, and Blue Fox). A ring of automatic data buoys with a diameter of 600 km was positioned around the stations to provide position data for verifying the model.

Funding was provided to integrate data on coastal sea ice dynamics into the AIDJEX model to improve the predictive capability. Deformation data were obtained from a National Oceanic and Atmospheric Administration unmanned buoy array to assess the influence of shorefast ice on the movement of multi-year ice of the Arctic Ocean.

Division of Ocean Sciences - This NSF division provides grants to the University of Alaska for oceanographic ship support, marine technician expenses, and equipment costs. Recent projects using ship time have included studies of silicon dynamics in the sea; sedimentation dynamics in an active valley-glacier fjord environment; elements of the sea-grass ecosystem; beryllium distribution in the marine environment, and processes and resources of the Bering Sea shelf.

The biological oceanography program of the Division of Ocean Sciences has recently supported one arctic project to identify factors responsible for structuring benthic communities in the southern Beaufort Sea. Distribution, abundance, and diversity of benthic fauna from the coastal to the lower bathyal zone will be described and examined, with correlations made between environments and biological features of the Beaufort Sea. Effects of ice gouging, river input of organics, patchy sediment distribution, cold bottom temperatures, and generally low levels of primary production will be emphasized.

The physical oceanography program has supported field studies of the transport of arctic water to the North Atlantic.

Department of Commerce.

The National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce has considerable arctic responsibility, outlined below.

National Ocean Surveys - This office is responsible for the collection of hydrographic physical and geophysical data, as well as precise positioning information for offshore boundary delineation. Charts containing collected information are prepared. Approximately $575,000 is spent annually on compiling and publishing these charts. Approximately 340,000 square kilometers of Alaskan waters already have been covered by 224 nautical charts. Other surveys are conducted to update tide and tidal current predictions, to develop baseline water circulation data for ecological studies, and to redefine tidal datums for determining land movement and shoreline changes. Additionally, tide observations in Alaskan waters are conducted at 16 control stations

and 40 secondary stations.

Coastal Zone Management (CZM) - Working with the state of Alaska, the Office of CZM provides a balance between economic development and environmental protection in the state.

National Weather Service - Weather information is collected and analyzed, and forecasts are made for ships on the high seas in accordance with international agreements under the World Meteorological Organization and the Safety of Life at Sea Convention. Responsibilities also include providing storm warnings to coastal areas.

Sea Grant - The Office of Sea Grant provides support for academic programs related to the development of marine resources, including biological, engineering, economics, and legal aspects.

Sea Grant support of 4-1/2 year investigation of the dynamics and properties of sea ice along the arctic coast ended in fiscal 1976. Emphasis was on determining ice salinity and crystal structure as a function of time during spring melting, on monitoring the in-situ stresses in the shorefast ice, on measuring the stress and strain of sea ice as brine drainage progressed, and on continuing operation of the ice radar at Point Barrow.

Environmental Data Service - This office archives and provides information on the oceanic environment and living and non-living resources.

National Environmental Satellite Service (NESS) - This is the principal office within NOAA for environmental satellite development and for the archiving of satellite data.

The NESS has made sea ice remote sensing investigations for several years. The objectives are 1) to design and implement experiments that will help develop sea ice dynamic models and prediction techniques, and 2) to determine the best airborne and spaceborne sensors and data handling techniques for providing information for sea ice modeling predicting.

Outer Continental Shelf Environmental Assessment Program - This program is conducted for the Bureau of Land Management of the Department of Interior to assess the likely effects on the environment of offshore oil development in Alaska.

U.S. Maritime Administration (MARAD) - MARAD, within the Department of Commerce, supports commercial shipping incentives for ships built and operating under the U.S. flag; MARAD is organizationally separate from NOAA.

The conceptual design of a nuclear icebreaking tanker was part of a continuing Maritime Administration program for exploring systems to develop and transport raw materials from the arctic coastal and offshore regions to the continental United States. Economics, opera-

tions, and safety were considered in the study of using tankers to transport oil from the arctic area as an alternative to a proposed pipeline to mid-America. Previous projects have dealt with requirements for arctic marine commerce, design of a drilling support ship, and design of a submarine transportation system.

Department of Interior.

Bureau of Land Management (BLM) - The BLM is responsible for leasing offshore lands and conducts outer continental shelf baseline studies and monitoring programs. Studies relate to toxicity data, delta-front sediment stability, bathymetric maps, faunal succession, ecological investigations of production and drill sites, cultural resource studies, and physical oceanographic studies. In Alaska, the BLM has contracted with NOAA to carry out an environmental assessment program in the OCS areas which addresses oil development in terms of natural hazards, pollution transport, and effects on the environment and biota.

U.S. Geological Survey (USGS) - The USGS is responsible for assessing marine oil and gas resources and geological hazards, regulating OCS operations, and assuring that offshore petroleum operations take into account the conservation of the environment and resources.

The President's Council on Environmental Quality (CEQ).

This organization is concerned with assessing the quality of the environment, setting pollution standards, and enforcing pollution abatement regulations.

Department of Energy (DOE).

DOE's Office of Offshore Technology undertakes research which will enhance the development of offshore oil and gas resources. Recent polar-related projects include true element cycling studies in Alaskan coastal waters and a study to determine the effects of petroleum hydrocarbons on coastal marine organisms.

Environmental Protection Agency (EPA).

The EPA, like the Council on Environmental Quality is charged with determining the need for pollution controls and setting and enforcing pollution standards. The EPA has undertaken a project to relate a defined chronic input of petroleum in an intertidal environment to the biological changes in the organisms and in community levels. Oil seeps along the Gulf of Alaska have been investigated to provide data on long-term, low-level input of petroleum into the marine intertidal environment. Specific tests for hydrocarbons, photosynthetic activity, and nutrient chemistry have been made at Oil Bay (on Cook Inlet about 480 km south of Anchorage).

Department of Transportation (DOT).

The U.S. Coast Guard is responsible for maritime safety and pollution control, including providing icebreaker services, search and rescue operations, navigation, ensuring safety of life at sea, and enforcing regulations pertaining to design, construction, and operation of floating structures, either of U.S. Registry or foreign ships operating in U.S. waters. The Office of Pipeline Safety of the DOT ensures the proper design and operation of pipeline transportation systems within the United States.

Department of Health, Education, and Welfare (HEW) and Department of Labor (DOL).

The National Institute of Occupational Safety and Health of HEW supports research in occupational health. The Occupational Safety and Health Agency (OSHA) of the Department of Labor sets standards to be met by government and industrial organizations. While arctic areas, at present, do not have polar-unique, ocean occupational standards, these regions do present special problems to workers and both NIOSH and OSHA could very well take active roles in this regard in the future.

National Aeronautical and Space Administration (NASA).

NASA's Office of Applications assures that satellite technology is made available to meet the requirements of other agencies. In oceanic and polar efforts, this office works closely with the National Environmental Satellite Service of NOAA.

One recent polar-oriented NASA-supported project made use of a specially equipped airplane in ongoing programs for designing, developing, testing, and demonstrating passive and active microwave remote sensing techniques for marine-related applications. Tests have been conducted over the ice shear zone off the north coast of Alaska, where offshore oil and gas exploration activities are being considered. Tests were conducted of visual and infrared films, passive microwave, and radar remote sensors simultaneously during the flights. Preliminary data analysis has led investigators to recognize the importance of using a variety of remote sensing instruments to obtain information of the interactions, characteristics, and movements of pack ice and shorefast ice. As a result of these investigations, Seasat-A's synthetic-apperture imaging radar system should be able to monitor sea ice drift.

NASA also flew missions over the Bering and Chukchi Seas in support of the Bering Sea Marine Mammal Experiment. Use was made of infrared remote sensors and photography to obtain information on the population of marine mammals on the ice.

Department of Defense.

The Navy Department's basic national defense responsibility is the protection of life and property of U.S. citizens. It also maintains an ocean engineering operation capability. To accomplish its main objective, the Navy maintains an oceanic surveillance program; in arctic regions, this requires a strong research program to provide fundamental oceanic data necessary for evaluating present capability and for providing a basis for the development of future systems. The Naval arctic research programs emphasize detailed knowledge of ice conditions, ice prediction capability, and the effect of the environment on sonar detection capability and on weapon systems. In ocean engineering operations, the Navy maintains a national capability for the underwater search and recovery of U.S. aircraft and for the salvage of Navy and commercial ships. This capability includes the development of diver physiology and logistic support and has included operations in arctic waters.

The Army Corps of Engineers, in its civil works responsibilities, exercises regulatory authority over the construction of any structures in or over navigable waters. The Outer Continental Shelf Lands Act extends this regulatory authority to artificial islands and fixed structures on the U.S. Outer Continental Shelf where the structure may affect navigation. The Corps also has regulatory authority over dredged or fill material from navigable waters and associated disposal sites.

The Army Corps of Engineers also operates the Cold Region Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire. The CRREL is the principal R&D center in the United States for research and studies into most aspects of cold region science and technology. Its Special Report 175 lists CRREL's contributions, including sea ice, ice engineering, and other relevant topics. Report 12 lists the contributions made by government agencies and other organizations in the U.S. and elsewhere in cold region science and engineering.

CRREL maintains a special ice engineering facility tank and flume and model basins where most of the relevant tests can be made. In addition, cold rooms and specialized laboratories in the various scientific and engineering disciplines are available. An advanced frost-effects research facility is scheduled for construction in 1981.

Department of State (DOS).

The State Department has an interest in arctic activities where there are international considerations or implications for U.S. foreign policy. This includes promoting cooperation among nations in scientific research and in environmental protection. The department also cooperates with government and private agencies, whenever appropriate, to facilitate international aspects of arctic research. In addition, it has the responsibility to conduct negotiations on international agreements, such as those currently underway for the extension of the Antarctic Treaty and the Law of the Sea Conferences. The department calls upon other agencies and the private sector for technical expertise in these negotiations.